Published in final edited form as:

J Dev Orig Health Dis. 2010 October ; 1(5): 329–337. doi:10.1017/S2040174410000309.

The relationship of birthweight, muscle size at birth and postnatal growth to grip strength in 9 year-old Indian children: findings from the Mysore Parthenon Study:

Birthweight and grip strength at 9

James G Barr, BSc¹, Sargoor R Veena, MBBS², K N Kiran, MSc², Andrew K Wills, PhD¹, Nicola R Winder, MSc¹, Sarah Kehoe, MSc¹, Caroline HD Fall, DM¹, Avan A Sayer, PhD¹, and Ghattu V Krishnaveni, PhD^{*,2}

¹MRC Epidemiology Resource Centre, University of Southampton, UK

²Epidemiology Research Unit, Holdsworth Memorial Hospital, Mysore, South India

Abstract

Fetal development may permanently affect muscle function. Indian newborns have a low mean birthweight, predominantly due to low lean tissue and muscle mass. We aimed to examine the relationship of birthweight, and arm muscle area (AMA) at birth and post-natal growth to hand-grip strength in Indian children. Grip strength was measured in 574 children aged 9 years, who had detailed anthropometry at birth and every 6-12 months post-natally. Mean (standard deviation (SD)) birthweight was 2863 (446) g. At 9 years, the children were short (mean height SD -0.6) and light (mean weight SD -1.1) compared with the World Health Organization growth reference. Mean (SD) grip strength was 12.7 (2.2) kg (boys) and 11.0 (2.0) kg (girls). Weight, length and AMA at birth, but not skinfold measurements at birth, were positively related to 9-year grip strength ($\beta=0.40$ kg per standard deviation increase in birthweight, $p<0.001$; and $\beta=0.41$ kg per standard deviation increase in AMA, $p<0.001$). Grip strength was positively related to 9-year height, body mass index and AMA and to gains in these measurements from birth to 2 years, 2-5 years and 5-9 years ($p<0.001$ for all). The associations between birth size and grip strength were attenuated but remained statistically significant for AMA after adjusting for 9-year size. We conclude that larger overall size and muscle mass at birth are associated with greater muscle strength in childhood, and that this is mediated mainly through greater post-natal size. Poorer muscle development *in utero* is associated with reduced childhood muscle strength.

Keywords

Grip strength; birthweight; children; arm muscle area

Introduction

Muscle strength is important for the performance of everyday activities. There is growing recognition of a relationship between muscle strength and general health¹. Epidemiological studies in adults have shown that lower grip strength is associated with higher overall mortality and an increased risk of coronary heart disease, type 2 diabetes and metabolic

* Author for correspondence: Dr GV Krishnaveni, Post Box 38, Epidemiology Research Unit, Holdsworth Memorial Hospital, Mandi Mohalla, Mysore 570021, India. Phone: 0091-821-2529347. Fax: 0091-821-2565607. gv.krishnaveni@gmail.com.

Statement of Interest: None

syndrome²⁻⁹. The main known determinants of muscle strength in adults include sex, body size, age, physical activity, genetic and hormonal influences, nutrition and levels of inflammation^{10, 11}. Factors associated with muscle strength in children are less well established but include age, sex and free fat mass^{12,13}. Muscle strength increases throughout childhood and adolescence, peaking in young adulthood. It is maintained into middle age before starting to decline¹. Muscle strength in later life therefore reflects both the peak reached and the rate of loss.

There is increasing interest in the early life determinants of muscle strength; studies have shown that birthweight is positively related to muscle strength in adult life¹⁴⁻¹⁶. Three studies of children, including Canadian¹⁷ and Guatemalan¹⁸ adolescents, and 5-year old Australian children¹⁹, have shown higher grip strength in children of normal birthweight than in those of low birth weight. As far as we know there have been no studies of children representing the full 'normal' range of birth weights. No studies have examined associations of grip strength with other birth measurements, apart from weight, to determine whether grip strength is specifically related to muscle size at birth.

Mean birthweight in India is low compared to that of white caucasian babies born in high-income countries^{20,21}. We have shown that this results predominantly from lower lean tissue and muscle mass at birth^{20,21}. Studies in India and elsewhere have shown associations between lower birthweight and reduced lean body mass in later childhood or adult life²²⁻²⁴. Small size at birth, and specifically small muscle size at birth, may therefore have long-term adverse effects on physical capacity. The Parthenon birth cohort study in Mysore, India, included detailed anthropometry at birth on a large sample of healthy babies, representing the full range of birth size in India. We have used data from this cohort to test the hypothesis that lower weight and smaller muscle size at birth (as measured by arm muscle area (AMA)) are associated with reduced grip strength at the age of 9 years.

Methods

The Mysore Parthenon Study (Figure 1) is a prospective birth cohort study, initiated in 1997-1998^{25,26}. Women living in Mysore city or surrounding rural villages, booking consecutively into the antenatal clinic of the Holdsworth Memorial Hospital (HMH) and satisfying the recruitment criteria (willingness to participate, singleton pregnancy, gestational age <32 weeks and no prior history of diabetes) were enrolled into the study (67% of eligible women). Gestation was determined from the last menstrual period date, or a first trimester ultrasound scan if the last menstrual period date was uncertain. Of 830 women recruited, 674 delivered at HMH, and 663 of these were live births without major congenital anomalies (Figure 1).

The babies were measured by one of four trained observers within 72-hours of birth. Weight was measured to the nearest 5 g using a digital weighing scale (Seca, Germany), and crown-heel length to the nearest 0.1 cm using a Harpenden neonatal stadiometer (CMS Instruments, London, UK). Mid-upper arm circumference (MUAC) was measured to the nearest 0.1 cm with blank tape, which was marked and measured against a fixed ruler. Skinfolds (triceps and subscapular) were measured to the nearest 0.1 mm using Harpenden callipers (CMS Instruments). The average of three readings was used. AMA was calculated using first principles to derive the following formula²⁷:

$$\frac{(MUAC - \pi \text{ triceps skinfold})^2}{4\pi}$$

The children were subsequently followed up annually to the age of 5 years and then 6-monthly until 9.5 years. Follow-up at 1 year was on the child's first birthday (± 4 weeks) for children born at term and on the anniversary of the expected date of delivery (± 4 weeks) for preterm children. Follow-up visits from 2-9.5 years were on the child's birthday (± 4 weeks) and (additionally after 5 years) 6 months after the birthday (± 4 weeks) for all children.

At 9 and 9.5 years, 560 and 539 children were studied, respectively; 9.5 year results were used preferentially with age-adjusted 9-year data being used for 35 children (Figure 1). Grip strength was measured to the nearest 0.5 kg by one of 6 trained fieldworkers, using a Jamar dynamometer (Model J00105, Lafayette Instrument Company, Loughborough, UK). The measurer demonstrated the technique to each child, who was seated with their forearm resting on the arms of the chair with the wrist free. The child held the dynamometer with the fieldworker supporting its weight. Encouragement was given to the child throughout the procedure, to squeeze as tightly and for as long as possible until the maximum reading was obtained. Three readings were made with each hand, alternating between right and left hands, and the maximum of the 6 measurements was used for the analysis.

Anthropometry was performed using standardised methods. Weight was measured to the nearest 100 g using a digital weighing scale (Salter, UK). Standing height was measured to the nearest 1 mm using a wall-mounted stadiometer (Microtoise, CMS Instruments, UK). MUAC and triceps and subscapular skinfolds were measured as at birth. AMA was calculated in the same way as at birth.

Socio-economic status was assessed using the Standard of Living Index (SLI)²⁸, designed by the National Family Health Survey, which derives a score based on household sanitary facilities, water source, power supply, type and size of house, cooking fuel used, and ownership of property, land, livestock, and household assets. Higher scores indicate higher socio-economic status. The HMH patient-base comes mainly from 'middle-class' and 'lower-middle-class' socio-economic groups.

The main analysis sample comprised all children with birth data and grip strength measured at 9 or 9.5 years (N=574).

The project was approved by the HMH Research Ethics Committee and informed consent was obtained from parents and children.

Statistical analyses

Variables with skewed distributions (9-year skinfold thickness and body mass index (BMI)) were log transformed. Birth measurements were adjusted to a gestation of 40 weeks using linear regression. Grip strength and anthropometry values for children studied at 9 years were adjusted to 9.5 years using linear regression. Comparisons between groups were analysed using *t* tests, as were comparisons between the sexes. Associations between size at birth and grip strength were analysed using linear regression. We examined socio-economic status as a possible confounding variable, and included adjustment for this in regression models. We tested for sex differences in the association between birth size and grip strength by using interaction terms; none of the interactions were statistically significant and therefore both sexes were included in the final regression models. Anthropometry at birth and 9 years and SLI scores were converted to sex-specific within-cohort standard deviation (SD) scores in regression models to allow comparison of relative effect size. We also derived SD scores at birth and 9 years using the World Health Organization (WHO) growth reference, in order to describe the size of the Mysore children in an international context²⁹.

To measure associations of growth (changes in body size) at different ages postnatally with 9-year grip strength we derived 'conditional' variables for each body measurement for the age intervals birth-2 years, 2-5 years and 5-9 years. All anthropometric measurements were standardised using Cole's LMS method³⁰. Standardised anthropometric measurements at the end of a given interval were regressed on the standardised measurement at the beginning of the interval in order to obtain the conditional growth for that interval. These conditional variables were stratified by sex. The residuals were extracted (these represent the change in size observed during each interval, over and above what would be expected given the child's earlier size) and stored as SD scores to allow comparison of effects of growth at different ages. By construction, conditional SD scores for different age intervals are uncorrelated. This permits them to be simultaneously included in regression models, in order to identify associations between specific periods of postnatal growth and the outcome of interest. This approach eliminates some of the statistical problems associated with modelling longitudinal measurements of body size, which are usually highly correlated^{31,32}. Data were analysed using Stata version 10.1.

Results

Table 1 shows the characteristics of the children at birth and 9 years. The children were on average short, light and thin according to the WHO growth reference, both at birth and 9 years; the prevalence of low BMI and stunting at birth (BMI and length <-2 SDs) was 23% and 10% respectively; equivalent figures at 9 years were 26% and 7%. Boys were heavier and longer at birth than girls ($p=0.03$ and $p=0.002$, respectively), and had higher mean grip strength ($p<0.001$). Boys were also taller than girls ($p=0.04$) but there was no significant difference in weight.

Birth measurements

Birthweight was positively related to grip strength at 9 years (Table 2). A 1 SD increase in birthweight was associated with a 0.40 kg (0.18 SD) increase in grip strength. There were significant associations of a similar magnitude between grip strength, AMA, and length at birth. There was no significant association with sum of triceps and subscapular skinfolds at birth ($\beta=0.05$; 95% CI: -0.05, 0.16; $p=0.33$).

Post-natal growth

Greater gain in height, BMI and AMA during all periods of post-natal growth, over and above that expected given the child's earlier size, were associated with higher grip strength (Figure 2). In contrast, skinfold measurements at birth, infancy and early childhood were unrelated to grip strength.

Current size and socio-economic status

Grip strength was positively related to 9-year BMI, height and AMA (Table 2), but not skinfold thickness. Mean grip strength was lower by -0.81 kg (95% CI: -1.37, -0.24) in boys and -1.26 kg (95% CI: -1.79, -0.72) in girls who were of low BMI, and by -1.93 kg (95% CI: -3.11, -0.96) in boys and -2.15 kg (95% CI: -2.99, -1.31) in girls who were stunted, compared to children of normal BMI and height. Grip strength was higher in children of higher socio-economic status (Table 2).

Birth size, 9-year size and SLI scores were inter-correlated. For example, 9-year height and AMA rose by 0.31 SD and 0.26 SD per SD increase in birth length and AMA, respectively, and by 0.23 SD and 0.15 SD per SD increase in SLI score. After adjusting for 9-year size, the associations between size at birth and grip strength were greatly attenuated, and no longer statistically significant for birthweight and length but remained statistically

significant for AMA (Table 3). The results were similar if we further adjusted for 9-year AMA ($\beta=0.16$, 95% CI: 0.00, 0.32; $p=0.047$). The relationship between birthweight and grip strength was the same in the whole sample ($N=574$) and the subset of 560 children that were analysed in table 3. There were no significant interactions between birthweight and 9-year size in relation to grip strength.

Discussion

Summary of findings

We measured grip strength in a large sample of healthy 9-year-old South Indian children from across the whole range of size at birth. The children were short and thin by international standards, both at birth and 9 years. Grip strength was positively related to weight, length and AMA at birth. Additionally, greater gain in BMI, height and AMA post-natally, predicted higher grip strength.

The associations between birth size and grip strength were greatly attenuated and no longer statistically significant for birthweight and length after adjusting for 9-year body size, statistical significance remained only for AMA, suggesting that, if causal, post-natal growth is on the causal pathway.

Strengths and limitations

Strengths of the study were that it included a large sample of healthy children, who had detailed standardised measurements, not just weight, at birth and at least annually up to the age they were studied. There was minimal loss to follow-up. The children were all born in one hospital, which could limit the representativeness of the sample. The Holdsworth Memorial Hospital is in a poor area of Mysore City, and offers concessions for poorer patients, but attracts patients from a wide spectrum of socio-economic status. We consider these children to be representative of low-middle class urban South Indian children.

Birth size and grip strength

The positive association between birthweight and grip strength was consistent with, and similar in magnitude to, associations seen in other studies in children and adults¹⁴⁻¹⁹. It suggests a link between pre-natal nutrition and/or growth and muscle function in later life. Primary muscle development begins in the human fetus at 8-10 weeks gestation, followed by the formation of secondary muscle fibres at 10-18 weeks^{33,34}. By 20 weeks these become homogeneous and undergo maturation and differentiation. After birth, muscle growth is primarily achieved through hypertrophy of existing fibres. The importance of fetal development for the accrual of muscle mass is indicated by a number of studies showing associations between birthweight and lean body mass and/or muscle mass in later life^{22, 35-42}. A link between body size at birth and later muscle size is therefore well established. The relationship of grip strength to birthweight, length and AMA at birth, and the much weaker relationships with skinfolds at birth, suggests that it is muscle size at birth rather than overall size that mediates these relationships. However, in an observational study it is impossible to say whether environmental factors, like maternal nutrition, or genetic factors are responsible for the relationship between birthweight and grip strength.

Post-natal growth and grip strength

Larger size at birth tends to 'track' throughout childhood, and although lower birthweight is often associated with compensatory or 'catch up' growth in the immediate post-natal period, higher birthweight is associated with faster childhood growth and larger size throughout childhood⁴³. Our data suggest that this could explain the higher grip strength observed in children who were larger at birth. In addition, any increase in height, BMI and AMA during

infancy and childhood, over and above what would be expected from larger size at birth, was also associated with higher grip strength. Overall, children who have grown faster at any prior stage of development and who have grown larger muscles, either because of better nutrition, or faster maturation, or genetic influences, have greater muscle strength. This is in keeping with other studies of grip strength in children, which have consistently reported strong correlations between overall size and/or muscle mass and grip strength^{13,44,45}. The time periods we chose for studying postnatal growth were selected to provide a measure of growth during infancy (0-2 years), early childhood (2-5) and late childhood (5-9). Although reference data for grip strength in children are scarce, mean grip strength in the Mysore children, who were short and thin according to the WHO growth reference, was lower than in recent studies of Spanish children (boys 15.0 kg and girls 13.9 kg at 10 years) and Swedish children (boys 14.0 kg and girls 13.0 kg at 9 years) who were also taller^{44,45}.

Studies in adults have shown that the positive relationship between grip strength and birthweight is attenuated but remains significant after adjustment for current height and weight^{14,46}. This has been explained by a postulated effect of developmental influences on muscle quality as well as quantity. Our findings for AMA at birth are consistent with this. However the attenuations of the associations in Mysore after adjusting for current size suggests that effects on muscle quantity dominate in childhood when muscle growth is still occurring, and effects on muscle quality appear predominantly in later life.

Other factors related to grip strength

Apart from body size, other 'current' factors related to grip strength in Mysore were gender and socio-economic status. Higher grip strength in boys than girls is consistent with other studies in children^{13,44,45}, and with greater height in boys (although there was no difference in AMA at this age). Socio-economic status was positively related to grip strength, and like birth size, this appeared to be partly mediated by 9-year size.

Conclusion

This study has shown, in a large sample of children representing the full range of birth and childhood size for an Indian population, that larger muscle size at birth and faster muscle growth post-natally are associated with greater muscle strength. Further follow-up of these children will be required to determine whether this association persists, resulting in greater peak muscle strength.

Acknowledgments

We are grateful to the women and children who participated, to Dr SC Karat, the current Director, and Dr BDR Paul, former Director of HMH, and the obstetric and paediatric consultants. We thank Jayakumar, Geetha, Saroja, Chachyamma, Tony Gerald, Tony Clifford, Shobha, Gopal Singh, Nalinakshi, Rumana, Jane Pearce and Patsy Coakley for their substantial contributions. We also thank Sneha-India for its support.

Funding: The study was funded by the Parthenon Trust, The Wellcome Trust and the Medical Research Council, UK.

References

1. Aihie Sayer A, Cooper C. Aging, sarcopenia and the life course. *Rev Clin Gerontol*. 2007; 16:265–274.
2. Rantanen T, Guralnik JM, Foley D, et al. Midlife hand grip strength as a predictor of old age disability. *JAMA*. 1999; 281:558–560. [PubMed: 10022113]
3. Syddall H, Cooper C, Martin F, Briggs R, Aihie Sayer A. Is grip strength a useful single marker of frailty? *Age Ageing*. 2003; 32:650–656. [PubMed: 14600007]

4. Sayer AA, Dennison EM, Syddall HE, Gilbody HJ, Phillips DI, Cooper C. Type 2 diabetes, muscle strength, and impaired physical function: the tip of the iceberg? *Diabetes Care*. 2005; 28:2541–2542. [PubMed: 16186295]
5. Sayer AA, Syddall HE, Dennison EM, et al. Grip strength and the metabolic syndrome: findings from the Hertfordshire Cohort Study. *QJM*. 2007; 100:707–713. [PubMed: 17951315]
6. Gale CR, Martyn CN, Cooper C, Sayer AA. Grip strength, body composition, and mortality. *Int J Epidemiol*. 2007; 36:228–235. [PubMed: 17056604]
7. Rantanen T, Harris T, Leveille SG, et al. Muscle strength and body mass index as long-term predictors of mortality in initially healthy men. *J Gerontol A Biol Sci Med Sci*. 2000; 55:M168–M173. [PubMed: 10795731]
8. Rantanen T, Volpato S, Ferrucci L, Heikkinen E, Fried LP, Guralnik JM. Handgrip strength and cause-specific and total mortality in older disabled women: exploring the mechanism. *J Am Geriatr Soc*. 2003; 51:636–641. [PubMed: 12752838]
9. Sayer AA, Syddall HE, Martin HJ, Dennison EM, Roberts HC, Cooper C. Is grip strength associated with health-related quality of life? Findings from the Hertfordshire Cohort Study. *Age Ageing*. 2006; 35:409–415. [PubMed: 16690636]
10. Rolland Y, Czerwinski S, Abellan van Kan G, et al. Sarcopenia: its assessment, etiology, pathogenesis, consequences and future perspectives. *J Nutr Health Aging*. 2008; 12:433–450. [PubMed: 18615225]
11. Morley JE, Baumgartner RN, Roubenoff R, Mayer J, Nair KS. Sarcopenia. *J Lab Clin Med*. 2001; 137:231–243. [PubMed: 11283518]
12. Lehman JB, Kafko M, Mah L, Mosquera L, Reilly B. An exploratory look at hand strength and hand size among preschoolers. *J Hand Ther*. 2002; 15:340–346. [PubMed: 12449348]
13. Sartorio A, Lafortuna CL, Pogliaghi S, Trecate L. The impact of gender, body dimension and body composition on hand-grip strength in healthy children. *J Endocrinol Invest*. 2002; 25:431–435. [PubMed: 12035939]
14. Sayer AA, Syddall HE, Gilbody HJ, Dennison EM, Cooper C. Does sarcopenia originate in early life? Findings from the Hertfordshire Cohort Study. *J Gerontol*. 2004; 59A:930–934.
15. Inskip HM, Godfrey KM, Martin HJ, Simmonds SJ, Cooper C, Aihie Sayer A. Size at birth and its relation to muscle strength in young adult women. *J Int Med*. 2007; 262:368–374.
16. Sayer AA, Syddall H, Martin H, Patel H, Baylis D, Cooper C. The developmental origins of sarcopenia. *J Nutr Health Aging*. 2008; 12:427–432. [PubMed: 18615224]
17. Rogers M, Fay TB, Whitfield MF, Tomlinson J, Grunau RE. Aerobic capacity, strength, flexibility, and activity level in unimpaired extremely low birth weight (<or=800 g) survivors at 17 years of age compared with term-born control subjects. *Pediatrics*. 2005; 116:e58–e65. [PubMed: 15997047]
18. Martorell R, Ramakrishnan U, Schroeder DG, Melgar P, Neufeld L. Intrauterine growth retardation, body size, body composition and physical performance in adolescence. *Eur J Clin Nutr*. 1998; 52(Suppl 1):S43–S52. [PubMed: 9511019]
19. Ford GW, Kitchen WH, Doyle LW. Muscular strength at 5 years of children with a birthweight under 1500 g. *Aust Paediatr J*. 1988; 24:295–296. [PubMed: 3228397]
20. Yajnik CS, Fall CHD, Coyaji KJ, et al. Neonatal anthropometry: the thin-fat Indian baby; the Pune Maternal Nutrition Study. *Int J Obesity*. 2003; 27:173–180.
21. Krishnaveni GV, Hill JC, Veena SR, et al. Truncal adiposity is present at birth and in early childhood in South Indian children. *Indian Pediatrics*. 2005; 42:527–538. [PubMed: 15995269]
22. Singhal A, Wells J, Cole TJ, Fewtrell M, Lucas A. Programming of lean body mass: a link between birth weight, obesity and cardiovascular disease? *Am J Clin Nutr*. 2003; 77:726–730. [PubMed: 12600868]
23. Rogers IS, Ness AR, Steer CD, et al. Association of size at birth and dual-energy X-ray absorptiometry measures of lean and fat mass at 9 to 10 y of age. *Am J Clin Nutr*. 2006; 84:739–747. [PubMed: 17023699]
24. Joglekar CV, Fall CH, Deshpande VU, et al. Newborn size, infant and childhood growth, and body composition and cardiovascular disease risk factors at the age of 6 years: the Pune Maternal Nutrition Study. *Int J Obes (Lond)*. 2007; 31:1534–1544. [PubMed: 17653070]

25. Hill JC, Krishnaveni GV, Annamma I, Leary SD, Fall CH. Glucose tolerance in pregnancy in South India: relationships to neonatal anthropometry. *Acta Obstet Gynecol Scand.* 2005; 84:159–165. [PubMed: 15683377]
26. Krishnaveni GV, Hill JC, Leary SD, et al. Anthropometry, glucose tolerance, and insulin concentrations in Indian children: relationships to maternal glucose and insulin concentrations during pregnancy. *Diabetes Care.* 2005; 28:2919–2925. [PubMed: 16306555]
27. Jelliffe DB, Jelliffe EPP. Prevalence of protein-calorie malnutrition in Haitian preschool children. *Am J Public Health Nations Health.* 1960; 50:1355–1366. [PubMed: 14407045]
28. International Institute for Population Sciences (IIPS) Operations Research Centre (ORC) Macro 2001. National Family Health Survey (NFHS-2), India, 1998-99. IIPS; Maharashtra, Mumbai:
29. World Health Organization. [Accessed 08 July 2009] Child growth standards. Available from <http://www.who.int/childgrowth/software/en/>
30. Cole TJ, Green PJ. Smoothing reference centile curves: the LMS method and penalized likelihood. *Stat Med.* 1992; 11:1305–1319. [PubMed: 1518992]
31. Fall CHD, Sachdev HS, Osmond C, et al. Adult metabolic syndrome and impaired glucose tolerance are associated with different patterns of body mass index gain during infancy; data from the New Delhi birth cohort. *Diabetes Care.* 2008; 31:2349–2356. [PubMed: 18835958]
32. Adair LS, Martorell R, Stein AD, et al. Size at birth, weight gain in infancy and childhood, and adult blood pressure in five low and middle income country cohorts: When does weight gain matter? *Am J Clin Nutr.* 2009; 89:1383–1392. [PubMed: 19297457]
33. Gollnick PD, Timson BF, Moore RL, Riedy M. Muscular Enlargement and Number of Fibers in Skeletal-Muscles of Rats. *J Appl Physiol.* 1981; 50:936–943. [PubMed: 7228766]
34. Barbet JP, Thornell LE, Butler-Browne GS. Immunocytochemical characterisation of two generations of fibers during the development of the human quadriceps muscle. *Mech Dev.* 1991; 35:3–11. [PubMed: 1954149]
35. Gale CR, Martyn CN, Kellingray S, Eastell R, Cooper C. Intrauterine programming of adult body composition. *J Clin Endocrinol Metab.* 2001; 86:267–272. [PubMed: 11232011]
36. Phillips DIW. Relation of fetal growth to adult muscle mass and glucose tolerance. *Diabet Med.* 1995; 12:686–690. [PubMed: 7587007]
37. Kahn HS, Narayan KMV, Williamson DF, Valdez R. Relation of birthweight to lean and fat thigh tissue in young men. *Int J Obes.* 2000; 24:667–672.
38. Weyer C, Pratley RE, Lindsay RS, Tataranni A. Relationship between birthweight and body composition, energy metabolism and sympathetic nervous system activity later in life. *Obes Res.* 2000; 8:559–565. [PubMed: 11156431]
39. Loos RJF, Beunen G, Fagard R, Derom C, Vlietinck R. Birth weight and body composition in young adult men – prospective twin study. *Int J Obes.* 2001; 25:1537–1545.
40. Li H, Stein AD, Barnhardt HX, Ramakrishnan U, Martorell R. Associations between prenatal and postnatal growth and adult body size and composition. *Am J Clin Nutr.* 2003; 77:1498–1505. [PubMed: 12791630]
41. Aihie Sayer A, Syddall HE, Dennison EM, et al. Birth weight, weight at 1 year of age, and body composition in older men: findings from the Hertfordshire Cohort Study. *Am J Clin Nutr.* 2004; 80:199–203. [PubMed: 15213049]
42. Sachdev HPS, Fall CHD, Osmond C, et al. Anthropometric indicators of body composition in young adults: relation to size at birth and serial measurements of body mass index in childhood; the New Delhi birth cohort. *Am J Clin Nutr.* 2005; 82:456–466. [PubMed: 16087993]
43. Tanner, JM. *Fetus into Man: Physical Growth from Conception to Maturity.* Castlemead publications; UK: 1989. p. 45
44. Marrodan Serrano MD, Romero Collazos JF, Moreno Romero S, et al. Handgrip strength in children and teenagers aged from 6 to 18 years: Reference values and relationship with size and body composition. *An Pediatr (Barc).* 2009; 70:340–348. [PubMed: 19268640]
45. Hager-Ross C, Rösblad B. Norms for grip strength in children aged 4–16 years. *Acta Paediatr.* 2002; 91:617–625. [PubMed: 12162590]

46. Kuh D, Bassey J, Hardy R, Aihie Sayer A, Wadsworth M, Cooper C. Birth weight, childhood size, and muscle strength in adult life: evidence from a birth cohort study. *Am J Epidemiol.* 2002; 156:627–633. [PubMed: 12244031]

Figure 1.

Height **Body mass index** **Arm muscle area** **Sum of triceps and subscapular skinfolds**

Figure 2. Change in grip strength SD score per SD change in conditional growth

Table 1
Descriptive statistics for the cohort of 574 Indian children

	Boys			Girls		
	N	Mean	(SD)	N	Mean	(SD)
Birth						
Birthweight (g)	275	2904	(463)	299	2825	(427)
Length (cm)	275	48.9	(2.3)	299	48.3	(2.2)
Arm muscle area (cm ²)	275	6.5	(1.2)	299	6.3	(1.1)
Sum of skinfolds (mm)*	275	8.2	(7.4, 9.3)	299	8.6	(7.6, 9.7)
Birthweight, WHO SD score	275	-0.99	(1.06)	299	-0.97	(1.02)
Length, WHO SD score	275	-0.52	(1.24)	299	-0.44	(1.19)
Body mass index, WHO SD score	275	-1.19	(1.19)	299	-1.16	(1.15)
9 years						
Body mass index (kg/m ²)*	275	14.4	(13.5, 15.6)	299	14.4	(13.4, 15.6)
Height (cm)	275	131.8	(5.4)	299	130.8	(6.0)
Arm muscle area (cm ²)	275	18.5	(3.1)	299	17.4	(3.2)
Sum of skinfolds (mm)*	275	15.1	(12.8, 18.7)	299	19.1	(15.6, 24.4)
Body mass index, WHO SD score	275	-1.3	(1.3)	299	-1.1	(1.2)
Height, WHO SD score	275	-0.5	(0.9)	299	-0.7	(1.0)
Grip strength (kg)	275	12.7	(2.2)	299	11.0	(2.0)
Standard of living index score	270	36.3	(8.0)	290	36.2	(8.5)

WHO - World Health Organization, SD - Standard deviation

Sum of skinfolds equals sum of triceps and subscapular skinfolds

* Median and inter-quartile range (skewed variable)

Birth			9 years										
	Weight	Length		Arm muscle area		Body mass index		Height		Arm muscle area		Standard of living index	
		Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Boys													
1	12.2 (2.0)	12.3 (2.0)	12.0 (2.2)	12.0 (2.3)	11.6 (1.9)	11.2 (1.9)	12.5 (2.1)						
2	12.7 (2.2)	12.6 (2.3)	12.7 (2.1)	12.7 (2.0)	12.9 (2.1)	12.9 (1.9)	12.4 (2.1)						
3	13.2 (2.4)	13.2 (2.1)	13.3 (2.3)	13.4 (2.5)	13.4 (2.4)	13.7 (2.6)	13.5 (2.4)						
β (95% CI)	0.42 (0.16, 0.67)	0.33 (0.07, 0.59)	0.48 (0.23, 0.74)	0.60 (0.35, 0.85)	0.82 (0.58, 1.07)	0.95 (0.72, 1.19)	0.47 (0.20, 0.73)						
p-value	0.002	0.01	<0.001	<0.001	<0.001	<0.001	0.001						
Girls													
1	10.6 (2.1)	10.3 (1.9)	10.5 (2.0)	10.1 (1.8)	9.9 (1.8)	9.7 (1.6)	11.0 (2.0)						
2	11.0 (2.0)	11.2 (2.2)	11.0 (2.0)	11.0 (1.8)	11.1 (2.0)	11.0 (1.9)	10.9 (1.9)						
3	11.7 (2.0)	11.4 (1.8)	11.7 (2.0)	12.2 (2.3)	12.0 (2.0)	12.4 (2.2)	11.4 (2.2)						
β (95% CI)	0.39 (0.16, 0.62)	0.35 (0.12, 0.58)	0.33 (0.11, 0.57)	0.74 (0.52, 0.96)	0.78 (0.56, 1.00)	0.86 (0.65, 1.07)	0.25 (0.03, 0.48)						
p-value	0.001	0.003	0.004	<0.001	<0.001	<0.001	0.03						

J Dev Orig Health Dis. Author manuscript; available in PMC 2013 June 05.

Table 3
Multiple regression analysis showing the association of 9 year grip strength (kg) with birthweight, adjusted for 9 year size and socio-economic status for 560 Indian children

	Univariate models			Multivariate model 1			Multivariate model 2			Multivariate model 3		
	β	95% CI	p	β	95% CI	p	β	95% CI	p	β	95% CI	p
Birthweight (g)	0.38	0.21, 0.55	<0.001	0.09	-0.07, 0.26	0.30	0.35	0.17, 0.52	<0.001	0.08	-0.08, 0.25	0.3
9 year height (cm)	0.80	0.63, 0.96	<0.001	0.64	0.46, 0.81	<0.001				0.61	0.43, 0.78	<0.001
9 year body mass index (kg/m ²)	0.67	0.50, 0.84	<0.001	0.46	0.28, 0.63	<0.001				0.45	0.28, 0.62	<0.001
Standard of living index	0.35	0.18, 0.52	<0.001				0.31	0.13, 0.48	0.001	0.15	-0.02, 0.31	0.08
Birth arm muscle area (cm ²)	0.40	0.23, 0.57	<0.001	0.20	0.04, 0.37	0.01	0.36	0.19, 0.53	<0.001	0.19	0.03, 0.35	0.02
9 year height (cm)	0.80	0.63, 0.96	<0.001	0.64	0.47, 0.81	<0.001				0.61	0.44, 0.78	<0.001
9 year body mass index (kg/m ²)	0.67	0.50, 0.84	<0.001	0.43	0.25, 0.60	<0.001				0.42	0.25, 0.59	<0.001
Standard of living index	0.35	0.18, 0.52	<0.001				0.31	0.13, 0.48	0.001	0.14	-0.03, 0.30	0.1

All models included sex; all exposure variables were Z-standardised. The univariate models contained each of the listed variables individually. The multivariable models included the birth size variable (birthweight or arm muscle area at birth) in addition (simultaneously) to the variables with data shown.