doi: 10.1111/j.1467-789X.2011.00869.x

Etiology and Pathophysiology

Body size and growth in 0- to 4-year-old children and the relation to body size in primary school age

T. Stocks[1,2], C. M. Renders[1,3], A. M. W. Bulk-Bunschoten[1], R. A. Hirasing[1], S. van Buuren[4,5] and J. C. Seidell[1,3]

[1]Department of Health Sciences, Faculty of Earth and Life Sciences and EMGO Institute for Health and Care Research, VU University, Amsterdam, the Netherlands; [2]Department of Surgical and Perioperative Sciences, Urology and Andrology, Umeå University, Umeå, Sweden; [3]Research Centre for the Prevention of Overweight Zwolle, Windesheim University of Applied Sciences, Zwolle, the Netherlands; [4]Netherlands Organisation for Applied Scientific Research, TNO Quality of Life, Prevention and Health Care, Leiden, the Netherlands; [5]Department of Methodology and Statistics, Faculty of Social Sciences, University of Utrecht, Utrecht, the Netherlands

Received 20 July 2010; revised 28 November 2010, 18 January 2011, 23 January 2011; accepted 24 January 2011

Address for correspondence: T Stocks, Institute of Health Sciences, VU University Amsterdam, De Boelelaan 1085, 1081 HV Amsterdam, the Netherlands. E-mail: tanja.stocks@urologi.umu.se

Summary

Excess weight in early life is believed to increase susceptibility to obesity, and in support of such theory, excess weight and fast weight gain in early childhood have been related to overweight later in life. The aim of this study was to review the literature on body size and growth in 0- to 4-year-old children and the association with body size at age 5–13 years. In total, 43 observational studies on body size and/or growth were included, of which 24 studies had been published in 2005 or later. Twenty-one studies considered body size at baseline, and 31 studies considered growth which all included assessment of weight gain. Eight (38%) studies on body size, and 15 (48%) on weight gain were evaluated as high-quality studies. Our results support conclusions in previous reviews of a positive association between body size and weight gain in early childhood, and subsequent body size. Body size at 5–6 months of age and later and weight gain at 0–2 years of age were consistently positively associated with high subsequent body size. Results in this review were mainly based on studies from developed Western countries, but seven studies from developing countries showed similar results to those from developed countries.

Keywords: Child, growth, overweight, weight gain.

obesity reviews (2011) **12**, 637–652

Introduction

Intrauterine and post-natal life is believed to be critical periods for programming of physiology and metabolism, and thereby of the predisposition of various metabolic diseases in later life, including obesity (1–3). Obesity with early onset results in an increase in fat cell number, which is thought to lead to increased susceptibility to obesity later in life (3). These theories are supported by data from observational studies which have shown that high weight in infancy is related to an increased risk of overweight in childhood, adolescence and adulthood (4–7). Two reviews considered body size in 0- to 2-year-olds and the relation to subsequent body size at any age (4,5). Baird *et al*. concluded from 24 studies of people born in 1927 onto 1994 that large body size and fast weight gain was related to an increased risk of obesity (4). In the other review, Ong & Loos calculated an odds ratio for obesity of 1.8 for an increase of ≥0.67 standard deviations (SD) in infant weight gain compared to an increase <0.67 SD (5). A more recent review by Singh *et al*., which includes publications up to February 2007, showed that large body size at any age between 0 and 18 years was related to adult overweight or obesity (6). These data indicate an association between body size in early life and in later life. However, a large number of new studies have emerged which were not included in previous reviews. Furthermore, the association has not been characterized in detail with respect to the child's age at measurement of growth.

We reviewed the literature on body size and growth in 0- to 4-year-old children and the association with subsequent body size. The association naturally becomes weaker with an increasing time between baseline and outcome measurement. Therefore, we restricted the outcome age to a maximum of 13 years which makes results between studies more comparable. We aimed to investigate the direction and strength of association in age groups, within the age range 0–4 years at baseline.

Methods

We searched for studies which reported on the association between body size or growth in children 0–4 years old, i.e. up to the fourth birthday, and body size at age 5–13 years. Measurements at baseline for body size and growth that were considered relevant were weight and height and any combinations thereof such as weight-for-height, body mass index (BMI, kg m^{-2}) and ponderal index (kg m^{-3}). Measurements of fatness such as skin-folds or waist circumference were also considered relevant. The same factors were included as outcome measures, with the exception of height. We considered articles for inclusion if the association was reported as relative risk or odds ratio, or if these estimates could be calculated from the reported data, i.e. relative risks for cohort studies, and odds ratios for case–control studies. Use of linear regression or similar analyses was also considered relevant, as was comparison of levels of exposure and levels of outcome. If none of these results were reported, data on correlation coefficients between relevant factors were included if these were available. Studies in which body size had been assessed only at birth and cross-sectional studies were not considered for inclusion. We restricted our search to publications in English language.

Studies fulfilling these criteria were searched for by a systematic narrative literature search. We first evaluated studies included in the reviews by Baird *et al.* (4), Ong & Loos (5) and Singh *et al.* (6), from which 18 studies were included. Another 25 studies were found through 'snowballing' (8). The snowball search included systematic citation tracking, and screening of reference lists of articles already identified for inclusion, and of key papers in childhood obesity research (e.g. Whitaker *et al.* (9), Ong *et al.* (10), Reilly *et al.* (11) and Cole *et al.* (12)). PubMed and ISI Web of Knowledge were used in the literature search. We included articles published before 1 March 2010.

The quality of studies was assessed according to the method suggested by the Centre for Reviews and Dissemination (13). We used the checklist for quality scoring as described by Baird *et al.* (14) with some modifications (Appendix S1). Cohort studies were evaluated by eleven criteria, and 12 criteria were used for case–control studies. The criteria were used to assess appropriateness with respect to study design, body size measurements, follow-up and controlling of presumable confounders. Confounders that were considered important to control for were sex, age, infant feeding, and parents' body size and socioeconomic status. Each criterion was scored as –1, 0 or 1, and the sum composed an overall quality score (mean = 0.3, SD = 3.0). Studies were categorized as low (<–1), medium (–1 to 1) or high (>1) quality. The evaluation was directly related to the results that we report in this review, which did not always correspond to the main analysis reported on in the study. Each study was evaluated independently by two authors, T. S. and C. M. R. or A. M. W. B., and disagreements were resolved through consensus between the three authors.

Results

Forty-one of the 43 included studies were cohort studies, and two were case–control studies. The study participants were born between 1959 and 2006, and studies were published in the periods: 1970–1984, eight studies; 1985–1999, zero studies; 2000–2004, 10 studies; and 2005–2010, 25 studies. Thirty-six studies (84%) originated from developed countries in Europe, North America and Australia/New Zeeland, and seven (16%) studies were from developing countries (15) in middle/south America, Asia and Africa (16–22). Twenty-one studies, based on data from 20 cohorts, reported on body size at baseline (Table 1), and 31 studies from 25 cohorts reported on growth (Table 2). Nine of these studies reported on both size and growth, of which in two studies the association with subsequent body size had been analysed differently for body size versus growth at baseline (38,40). We ranked the quality of these analyses differently, which resulted in different overall quality scoring. Thus, we report on study (or analysis) quality separately for body size and growth.

We rated six (29%) studies on body size to be of low quality, and eight (38%) studies were considered as high quality. The corresponding numbers for studies on growth were five (16%) low- and 15 (48%) high-quality studies. The most common sources of poor quality were high dropout rates in prospective studies or low participation rates in retrospective studies, and that measurements of body size or growth were poorly assessed or described. Other common sources of poor quality were the use of inappropriate statistical methods to assess the association between body size or growth and subsequent body size, and poor control of potential confounders. The majority of high-quality studies, 63% on body size and 73% on growth, were published in 2005 and later.

Table 1 Summary of studies reporting on body size at 0–4 years of age and the association with body size at 5–13 years of age, ordered by type of analysis and cohort

Study	*n* subjects* (% boys†), birth year	Exposure, age	Time exposure-outcome	Outcome, age	Analysis	Association‡	Quality
Reilly (2005) (11) Avon, UK	909 (51% boys), 1991–1992	Weight *z*, quartile 4 vs. 1–3, at age: (1) 8 months (2) 1.5 years	(1) 6.3 years (2) 5.5 years	BMI $z \geq 1.64$ (≥pc 95) for sex and age, at age 7 years	OR by logistic regression	OR, (1): 3.03 (1.89–4.85) OR, (2): 3.71 (2.29–6.00)	High
Nader (2006) (23) USA	555 (46% boys), 1991	BMI ≥pc 95 vs. <pc 95 at age: (1) 2 years (2) 3 years	(1) 10 years (2) 9 years	BMI, kg m^{-2}, ≥pc 95 at age 12 years	OR by logistic regression	OR, (1): 2.2 (0.8–6.1) OR, (2): 2.5 (0.9–7.2)	Medium
Huus (2007) (24) south-east Sweden	4292 (48% boys), 1997–1999	(1) BMI kg m^{-2} >pc 95 vs. ≤pc 95 for sex and age, at age 1 year 2) BMI kg m^{-2} >25 vs. ≤25 for sex and age on IOTF charts, at age 2.5 years	(1) 4 years (2) 2.5 years	(A) BMI >25 kg m^{-2} for sex and age on IOTF charts, at age 5 years (B) BMI >30 kg m^{-2} for sex and age on IOTF charts, at age 5 years	OR by logistic regression, adjusted for birth weight, parents' BMI, parents' education, parents' age, single parent, number of siblings	OR, (1A): 6.03 (4.65–7.83) OR, (1B): 6.57 (4.63–9.33) OR, (2A): 12.4 (10.4–14.6) OR, (2B): 25.5 (16.2–39.9)	Medium
Scholtens (2007) (25) the Netherlands	2347 (52% boys), 1996–1997	BMI, per kg m^{-2}, at mean age 1.0 year (SD: 0.1)	6.0 years	BMI >25 kg m^{-2} for sex and age on IOTF charts, at mean age 7.0 years (SD: 0.1)	OR by logistic regression, adjusted for sex, birth weight, age, overweight in mother and mother's education	OR: 1.48 (1.34–1.62)	Low
Touchette (2008) (26) Quebec, Canada	815–846 (47% boys), 1997–1998	Weight, per kg, at age: (1) 5 months (2) 2.5 years	(1) 5.6 years (2) 3.5 years	(A) BMI ≥25 kg m^{-2} for sex and age on IOTF charts, at age 6 years	OR by logistic regression	OR, (1): 1.42 (1.20–1.67) OR, (2): 1.62 (1.46–1.80)	Low
Stettler (2002) (27) — Collaborative perinatal project, USA, nationwide (Stettler), and Philadelphia (Johnston)	18 406 (50% boys), 1959–1965	Weight, per 100 g, at age 1 year	6 years	BMI, kg m^{-2}, >pc 95 for sex and age, at age 7 years	OR by logistic regression	OR: 1.05 (1.04–1.05)	High
Johnston (1978) (28)	146 (51% boys), 1960–1965	Weight-for-height >1 SD vs. <–1 SD, at age 1 years	9 years	(A) predicted weight for height, sex and age/actual weight ≥120% at age 10 years§ (B) triceps skin-folds, mm, >pc 90 for sex, age and race, at age 10 years§	RR calculated from contingency table	RR, (A): boys, 2.52 (0.58–11.1); girls, 5.51 (1.78–17.1) RR, (B): boys, 3.31 (1.26–8.67); girls, 8.27 (2.07–33.0)	Low
Poskitt (1977) (29) Dudley, UK	203 (49% boys), 1968–1970	Weight-for-age >120% vs. ≤120%, when height is at pc 50, at mean age 5 months (range: 0.5–12 months)	4.7 years	Weight-for-age >120% when height is at pc 50, at mean age 5.1 years (range: 4.3–6.4 years)	RR calculated from contingency table	RR: 9.38 (1.64–53.6)	Medium
Wilkinson (1977) (30) Newcastle, UK	42–48 cases (42% boys) and equal number of controls in analyses, 1960–1962	Weight >pc 90 vs. ≤pc 90 for sex and age, at age: (1) 6 months (2) 1 year	(1) 9.5 years (2) 9 years	Weight-for-height >pc 97 (cases) vs. pc 25–75 (controls), at age 10 years	OR calculated from contingency table	OR, (1): 2.00 (0.88–4.56) OR, (2): 1.62 (0.63–4.15)	Medium
Magarey (2003) (31) Adelaide, Australia	90 (57% boys), 1975–1976	BMI ≥25 vs. <25 kg m^{-2} for sex and age on IOTF charts, at age 2 years	9 years	BMI ≥25 kg m^{-2} for sex and age on IOTF charts, at age 11 years¶	RR calculated from contingency table	RR: 4.31 (1.95–9.51)	Low
Vanhala (2009) (32) Oulu, Finland	749 (51% boys), 1997	(1) BMI kg m^{-2} ≥pc 85 vs. <pc 85 for sex and age on IOTF charts, at age 3 years (2) BMI kg m^{-2} ≥pc 95 vs. <pc 95 for sex and age on IOTF charts, at age 3 years	4.3 years	BMI kg m^{-2} ≥pc 85 for sex and age on IOTF charts at mean age 7.3 years (SD: 0.3)	RR calculated from contingency table	RR, (1): 5.20 (3.97–6.82) RR, (2): 4.45 (2.99–6.65)	Low

Table 1 *Continued*

Study	n subjects* (% boys†), birth year	Exposure, age	Time exposure-outcome	Outcome, age	Analysis	Association‡	Quality
Fuentes (2003) (33) Finland	100 (55% boys), 1981–1982	(1) BMI, kg m^{-2}, tertile 3 vs. 1–2 for sex and age, at age 6 months (2) BMI, per kg m^{-2}, at age 6 months	6.5 years	(A) BMI, kg m^{-2}, tertile 3 at age 7 years (B) BMI, kg m^{-2}, at age 7 years	(1A): RR reported (2B): Beta by linear regression, adjusted for sex, birth weight, parent's education, obesity in parents, family history of CVD	(1A): RR, 1.5 (0.9–2.6) (2B): Beta, 0.53, $P < 0.001$	High
Gunnarsdottir (2003) (34) Iceland	90 (46% boys), birth year not reported	(1) Weight, per kg, at age 1 year (2) Height, per cm, at age 1 year	5 years	BMI, kg m^{-2}, at age 6 years	Beta by linear regression	Beta, (1): boys, 0.9 (0.3; 1.5); girls, 0.4 (–0.4; 1.2) Beta, (2): boys, 0.1 (–0.1; 0.3); girls, –0.02 (–0.2; 0.2)	High
Kinra (2005) (35) Plymouth, UK	1,335 (49% boys), 1989	Weight, per SD z, for sex and age, at age: (1) 6 weeks (2) 1.5 years	(1) 6.8 years (6.1–7.4 years) (2) 5.4 years (4.7–6.0 years)	BMI z for sex and age, at mean age 6.9 years (range: 6.2–7.5 years)	Beta by linear regression	Beta, (1): 0.19 (0.15; 0.24) Beta, (2): 0.29 (0.26; 0.33)	High
Gale (2007) (36) Southampton, UK	216 (52% boys), 1991–1993	Weight, per SD z, for sex at age 9 months	8.2 years	Fat mass index (fat mass [kg]/height [m][4.9]) z for sex at mean age 8.9 years (SD: 0.3)	Beta by linear regression, adjusted for baseline age	Beta: boys, 0.07 (–0.01; 0.15); girls, –0.06 (–0.25; 0.14)	High
Joglekar (2007) (19) Pune, India	698 (sex proportion not reported), 1994–1996	Per SD z: weight, height, mid-upper arm circumference (MUAC), subscapular skin-fold (SF), triceps SF, at age: (1) 6 months (2) 1 year	(1) 5.5 years (2) 5 years	Fat mass z at age 6 years	Beta by linear regression	Beta (1): weight, 0.35; height, 0.21; MUAC, 0.28; subscapular SF, 0.22; triceps SF, 0.19. $P < 0.001$ for all Beta (2): weight, 0.44; height, 0.26; MUAC, 0.35; subscapular SF, 0.26; triceps SF, 0.15. $P < 0.001$ for all	High
Kain (2009) (17) Santiago, Chile	441–617, sex proportion and birth year not reported	BMI, per SD z, for sex and age, at age:** (1) 1 month (2) 6 months (3) 1 year (4) 2 years (5) 3 years	(1) 4.9 years (2) 4.5 years (3) 4 years (4) 3 years (5) 2 years	BMI $z > 2$ vs. ≤ 1 for sex and age, at age 5 years	Difference in BMI at baseline age between children with BMI $z > 2$ vs. ≤ 1 at 5 years, by general linear model, adjusted for sex, birth weight, age, mother's BMI, mother's pregnancy smoking status, mother's pregnancy weight gain, presence of gestational diabetes or pre-eclamsia	Difference: (1): 0.21 (–0.06; 0.48) (2): 0.76 (0.46; 1.05) (3): 0.98 (0.73; 1.24) (4): 1.16 (0.91; 1.41) (5): 1.77 (1.49; 2.05)	High

Table 1 *Continued*

Study	*n* subjects* (% boys†), birth year	Exposure, age	Time exposure-outcome	Outcome, age	Analysis	Association‡	Quality
Dine (1979) (37) USA	476 (49% boys), birth year not reported	(1) Weight at age 6 months, 2 years and 4 years†† (2) BMI at age 6 months, 2 years and 4 years††	4.5 years, 3 years and 1 year	(A) Weight, kg, ≥pc 90 vs. <pc 90 at 5 years (B) BMI, kg m^{-2}, ≥pc 90 vs. <pc 90 at 5 years	Comparison of exposure level in children with weight and BMI higher vs. lower than pc 90 at 5 years, Student's *t*-test	Mean (SD): 1A, at 6 months: ≥pc 90, 8.5 (0.9) kg; <pc 90, 7.7 (0.9) kg, $P < 0.0001$ 1A, at 2 years: ≥pc 90, 13.9 (1.3) kg; <pc 90, 12.0 (1.2) kg, $P < 0.0001$ 1A, at 4 years: ≥pc 90, 19.7 (1.5) kg; <pc 90, 15.9 (1.5) kg, $P < 0.0001$ 2B, at 6 months: ≥pc 90, 17.6 (1.4) kg m^{-2}; <pc 90, 16.9 (1.4) kg m^{-2}, $P < 0.0001$ 2B, at 2 years: ≥pc 90, 17.6 (1.4) kg m^{-2}; <pc 90, 16.2 (1.4) kg m^{-2}, $P < 0.0001$ 2B, at 4 years: ≥pc 90, 18.3 (1.4) kg m^{-2}; <pc 90, 15.5 (0.7) kg m^{-2}, $P < 0.0001$	Medium
Vogels (2006) (38) Limburg, the Netherlands	105 (57% boys), 1990–1993	(1) Weight at age 1 year (2) Height at age 1 year (3) BMI at age 1 year	11.4 years (10–13 years)	BMI ≥25 kg m^{-2} (overweight) vs. <25 kg m^{-2} (normal) for sex and age on IOTF charts, at mean age 12.4 years (range: 11–14 years)	Comparison of exposure level at 1 year in overweight vs. normal-weight children at 12 years, Student's *t*-test	Mean (SD): (1): overweight, 10.2 (1.0) kg; normal, 9.8 (1.0) kg, $P = 0.2$ (2): overweight, 76.7 (2.1) cm; normal, 76.1 (3.2) cm, $P = 0.5$ (3): overweight, 17.3 (1.5) kg m^{-2}; normal 17.0 (1.4) kg m^{-2}, $P = 0.3$	Low
Law (2002) (39) Brompton, UK	346 (47% boys), 1975–1977	Weight *z* for sex and age, at 1 year	4 years (1–5 years)	Weight *z* for sex and age at 2–6 years, closest to the fifth birthday	Correlation coefficient	*r*: 0.58, $P < 0.001$	Medium
Blair (2007) (40) Auckland, New Zeeland	591 (49% boys), including 41% of subjects small for gestational age, 1995–1997	Fat mass % at mean age 3.9 years (range: 3.5–4 years)	3.4 years	Fat mass % at mean age 7.3 years (range: 7–8 years)	Correlation coefficient	*r*: 0.67, P<0.001	Medium

*Number of subjects refers to the number included in the analysis reported on here.
†Proportion boys in the analysis, or if not reported on in the study, in the full study group.
‡Confidence intervals correspond to 95% precision. Results are presented for the most adjusted model except for in cases where analysis of body size included adjustment for the same body size measure at birth, which rather displays change in body size between birth and the actual age. In such case results from another analysis is reported.
§Results were also reported for outcome age 9, 11 and 12 years. We report on the 10-year-olds because the age group included the largest number of subjects. Results for the age groups differed somewhat, but confidence intervals were very wide and were overlapping between the groups.
¶RR for outcome at age 8 years = 3.99 (1.63–9.74).
**Results were also reported for baseline ages 2 months, 4 months and 1.5 years, which followed the pattern of a more pronounced association with higher baseline age.
††Results were also reported for baseline ages 1 and 3 years, which followed the pattern of a more pronounced association with higher baseline age. Results for weight/height ratio and ponderal index showed that children who had high levels of these factors at 5 years had statistically higher levels at all baseline ages.
BMI, body mass index; CVD, cardiovascular disease; IOTF, International Task Force; pc, percentile; OR, odds ratio; RR, relative risk; SD, standard deviation; vs., versus; z, variable standardized into *z* distribution.

Table 2 Summary of studies reporting on growth between 0 and 4 years of age and the association with body size at 5–13 years of age, ordered by analysis type and cohort

Study		*n* subjects* (% boys†), birth year	Exposure, age	Time exposure outcome	Outcome, age	Analysis	Association‡	Quality
Stettler (2002) (21) Seychelles		5514 (48.5% boys), 1985–1990	Weight gain, per kg, between age 0 and 1 year	11 years	(A) BMI >25 kg m^{-2} for sex and age on IOTF charts, at age 12 years (B) BMI >30 kg m^{-2} for sex and age on IOTF charts, at age 12 years	OR by logistic regression, adjusted for sex, gestational age, birth weight, age, mother's BMI, parents' occupation	OR, (A): 1.46 (1.27–1.67) OR, (B): 1.59 (1.29–1.97)	High
Karaolis-Danckert (2006) (41) Germany		206 (50% boys), birth year not reported	Weight change $z > 0.67$ vs. ≤ 0.67 for sex and age, between age 0 and 2 years	5 years	BMI >25 kg m^{-2} for sex and age on IOTF charts at age 7 years	OR by logistic regression, adjusted for sex, gestational age, BMI at birth, mother's weight, mother's education, infant feeding	OR: 6.2 (2.4–16.5)	High
Eid (1970) (42) Sheffield, UK		224 (54% boys), 1961	Weight gain, kg, >pc 90 vs. ≤pc 90 for sex and age, between age 0 and 6 months	7.3 years (5.1–8.0 years)	Weight >20% higher than expected for height, sex and age, at mean age 7.8 years (range: 5.6–8.5 years)	RR calculated from contingency table	RR: 4.05 (0.94–17.5)	Low
Mellbin (1973) (43)		972 (48% boys), 1963	Weight gain, kg, >pc 97 vs. ≤pc 97 for sex, between age 0 and 3 months, or 1 and 4 months, or 9 and 12 months	6.2 years	Weight-for-height >20% than expected for sex, at mean age 7.2 years (SD: 3.3)	RR calculated from contingency table	RR: boys, 7.40 (2.41–22.7); girls, 1.33 (0.46–3.86)	Medium
Mellbin (1976) (44)	The studies by Mellbin *et al.* originate from the same cohort in Uppsala, Sweden	895 (47% boys), 1963	Weight gain, kg, >pc 97 during any 4-month period between age 0 and 1 year, or weight gain >pc 90 between age 0 and 1 year, or weight >pc 90 at age 1 year, vs. none of these criteria	9.5 years (8.8–10.2 years)	(A) Weight-for-height >20% than expected for sex, at mean age 10.5 years (range: 9.8–11.2 years) (B) Sum of triceps and subscapular skin-folds, mm, >pc 95 for sex, at mean age 10.5 years	RR reported	RR, (A): boys, 3.32, $P < 0.01$; girls, 1.61, $P > 0.05$ RR, (B): boys, 1.68, $P > 0.05$; girls, 1.75, $P > 0.05$	Medium
von Kries (2002) (45)		6483 (sex proportion not reported), 1992–1995	Weight gain, kg, top quartile vs. quartile 1–3 between age 0 and 1 year	4–6 years	A) BMI, kg m^{-2}, >pc 90 for sex and age, at age 5–7 years B) BMI, kg m^{-2}, >pc 97 for sex and age, at age 5–7 years	OR by logistic regression, adjusted for birth weight	OR, (A): 1.82 (1.52–2.18) OR, (B): 1.52 (1.09–2.11)	Low
Toschke (2004) (46)	Bavaria, Germany. Same cohort was used in study by von Kries and Toschke. Study by Beyerlein includes the cohort in von Kries and Toschke, and an additional study sample	4235 (sex proportion not reported), 1992–1995	Weight gain >9746 g (tertile 3) vs. ≤9746 g (tertile 1–2) between age 0–2 years	3–5 years	BMI >25 kg m^{-2} for sex and age on IOTF charts, at age 5–7 years	RR calculated from contingency table	RR: 4.76 (3.86–5.87)	Low
Beyerlein (2010) (47)		9698 (sex proportion not reported), 1992–1997	Weight gain, per kg, between age 0 and 2 years	4.1 (2.5–5.3) years	BMI *z* for sex and age at mean age 6.1 years (range: 4.5–7.3)	Beta by linear regression, adjusted for mother's BMI, mother's pregnancy smoking status, infant feeding, parents' education, TV watching at school entry	Beta: 0.37 (0.35; 0.39)	Low

Table 2 *Continued*

Study		*n* subjects* (% boys†), birth year	Exposure, age	Time exposure outcome	Outcome, age	Analysis	Association‡	Quality
Reilly (2005) (11)		487–522 (51% boys), 1991–1992	Weight change between age 0 and 1 year: (1) per 100 g (2) *z* for sex, and age, adjusted for gestational age; rapid (>0.67), normal (–0.67 to 0.67), slow (<–0.67)	6 years	BMI $z > 1.64$ (>pc 95) for sex and age, at age 7 years	OR by logistic regression, adjusted for sex, birth weight, parental obesity, mother's education, mother's pregnancy smoking status, hours of sleep and television watching at 2.5 years, diet at 3 years	OR, (1): 1.06 (1.02–1.10) OR, (2): rapid, 2.21 (1.30–3.8); normal, 1 (ref); slow, 0.46 (0.2–1.03)	High
Ong (2009) (48)	The study by Reilly *et al.* and the studies by Ong *et al.* originate from the same cohort: the Avon longitudinal study of parents and children, Avon, UK	2402 (0% boys), 1991–1992	Weight change per SD *z* for age or gestational age, between age: (1) 0 and 2 months (2) 2 and 9 months (3) 9 month and 1.5 years	(1) 9.8 years (2) 9.3 years (3) 8.5 years	Body size at age 10 years: (A) weight, kg (B) BMI, kg m^{-2} (C) fat mass index, kg m^{-2} (D) fat mass, % (E) fat mass/fat free mass ratio (F) BMI *z* >pc 85 for age	Beta by linear regression, or OR by logistic regression, adjusted for mother's education, and also height at 10 years for fat mass outcomes	Beta: (1): A, 0.99 (0.60; 1.38); B, 0.31 (0.15; 0.47); C, 0.15 (0.03; 0.27); D, 0.45 (0.06; 0.18); E, 0.03 (0.00; 0.05) (2): A, 0.86 (0.55; 1.17); B, 0.24 (0.12; 0.36); C, 0.09 (0.02; 0.17); D, 0.48 (0.31; 0.81); E, 0.03 (0.01; 0.05) (3): A, 1.01 (0.52; 1.50); B, 0.24 (0.06; 0.42); C, 0.05 (–0.09; 0.19); D, 0.07 (–0.42; 0.56); E, 0.00 (–0.03; 0.03) OR, 1 + 2 (0–9 months) F, 1.48 (1.27–1.60)	High
Ong (2000) (10)		705–848 (55% boys), 1991–1992	Weight change *z* for sex and age, adjusted for gestational age; rapid [+] (>0.67), normal [0] (–0.67 to 0.67), slow [–] (<–0.67), between age 0 and 2 years	3 years	*Z* for sex and age, at age 5 years, of: (A) weight (B) BMI Absolute level, at 5 years, of: (C) fat mass, kg (D) fat mass, % (E) waist circumference, cm	Comparison of body size at 5 years in weight change groups. ANOVA	Mean (SD): (A): [+], 0.87 (0.93); [0], 0.22 (0.87); [–], –0.29 (0.93) (B): [+], 0.82 (1.01); [0], 0.19 (0.87); [–], –0.07 (0.86) Mean (95% CI): (C): [+], 3.6 (3.4–3.7); [0], 3.0 (2.9–3.1); [–], 2.6 (2.5–2.8) (D): [+], 17.2 (16.6–17.7); [0], 15.8 (15.4–16.2); [–], 14.7 (14.2–15.2) (E): [+], 54.6 (54.2–55.1); [0], 52.7 (52.3–53.0); [–], 51.3 (50.9–51.8) *P*-value <0.0005 for all	High
Stettler (2002) (27)	The studies by Stettler *et al.* and Hemachandra *et al.* originate from the same cohort: the Collaborative Perinatal Project, USA	11 595 (50% boys), 1959–1965	Weight gain, per 100 g monthly gain, between age 0 and 4 months	6.7 years	BMI, kg m^{-2}, >pc 95 for sex and age, at age 7 years	OR by logistic regression, adjusted for sex, gestational age, birth weight, race, first-born status, mother's BMI, mother's education	OR: 1.38 (1.32–1.44)	High
Hemachandra (2007) (49)		29 710 (sex proportion not reported), 1959–1965	Weight change per SD *z* between age: (1) 0 and 4 months (2) 4 months and 1 year (3) 1 and 4 years	(1) 6.7 years (2) 6 years (3) 3 years	BMI, kg m^{-2}, at age 7 years	Correlation coefficient	*r*, (1): 0.10, $P < 0.01$ *r*, (2): 0.06, $P < 0.01$ *r*, (3): 0.38, $P < 0.01$	High

Table 2 *Continued*

Study	*n* subjects* (% boys†), birth year	Exposure, age	Time exposure outcome	Outcome, age	Analysis	Association‡	Quality
Gunnarsdottir (2003) (34) Iceland	90 (46% boys), birth year not reported	(1) weight gain, per kg, between age 0 and 1 year (2) weight gain/birth weight ratio between age 0 and 1 year (3) height gain, per cm, between age 0 and 1 year	5 years	BMI, kg m^{-2}, at age 6 years	Beta by linear regression	Beta, (1): boys, 1.1 (0.5; 1.7); girls, 0.6 (–17.8; 19.0) Beta, (2): boys, 2.9 (0.9; 4.9); girls, 2.0 (0.2; 3.8) Beta, (3): boys, 0.4 (0.2; 0.6); girls, 0.1 (0.08; 0.12)	High
Kinra (2005) (35) Plymouth, UK	1335 (49% boys), 1989	Weight change per SD *z* for sex and age between age: (1) 0 and 6 weeks (2) 6 weeks and 1.5 years	(1) 6.8 years (6.1–7.4) (2) 5.4 years (4.7–6.0)	BMI *z* for sex and age at mean age 6.9 years (range: 6.2–7.5)	Beta by linear regression, adjusted for birth weight	Beta, (1): 0.17 (0.12; 0.22) Beta, (2): 0.18 (0.14; 0.22)	High
Vogels (2006) (38) Limburg, the Netherlands	105 (57% boys), 1990–1993	Weight gain, per kg, between age 0 and 1 year	11.4 years (10–13)	Body size at mean age 12.4 years (range: 11–14): (A) BMI, kg m^{-2} (B) fat mass, %	Beta by linear regression, adjusted for sex, father's BMI, mother's eating behaviour	Beta, (A): 0.92 (0.33; 1.51) Beta, (B): 2.05 (0.42; 3.68)	Medium
Blair (2007) (40) Auckland, New Zeeland	591 (49% boys), including 41% of subjects small for gestational age, 1995–1997	Change/month in weight and height, *z* for sex and age, in quartiles (Q), between age: (1) 0 and 8.7 months (pc 25–75: 8.4–9.5) (2) 8.7 months and 3.9 years (pc 25–75: 3.8–3.9)	(1) 6.6 years (2) 3.4 years	Fat mass % at mean age 7.3 years (pc 25–75: 7.2–7.3)	Beta by linear regression, weighted for high proportion small for gestational age, and adjusted for sex, mother's BMI, mother's pregnancy age, h day^{-1} of watching TV, h day^{-1} sedentary activity	Beta, (1): weight change, Q1, 0 (ref); Q2, 1.4 (–0.6; 3.4); Q3, 4.3 (2.1; 6.6); Q4, 7.1 (3.8; 10.3), $P < 0.001$. Results for height change reported as ns Beta, (2): weight change, Q1, 0 (ref); Q2, 1.5 (–1.1; 4.1); Q3, 2.3 (–0.3; 4.9); Q4, 6.4 (3.5; 9.3), $P < 0.001$. Height change, Q1, 0 (ref); Q2, 0.9 (–1.2; 2.9); Q3, 1.4 (–1.1; 3.9); Q4, 4.7 (1.9; 7.4), $P = 0.007$	High
Gale (2007) (36) Southampton, UK	216 (52% boys), 1991–1993	Weight change per SD *z* for birth weight, between age 0 and 9 months	8.2 years	Fat mass index (fat mass [kg]/height [m][4.9]) *z* for sex at age 8.9 years (SD: 0.3)	Beta by linear regression, adjusted for birth weight, age, infant feeding and mother's: pre-pregnant BMI, height, pregnancy weight gain and pregnancy smoking status	Beta: boys, 0.20 (0.02; 0.38); girls, –0.08 (–0.26; 0.09)	High
Jones-Smith (2007) (20) Morelos, Mexico	163, sex proportion and birth year not reported	Change in body size per SD *z* for sex and age, between age 0 and 1 year, for: (1) BMI (2) height-for-age	4.1 years (3–5)	BMI at mean age 5.1 years (range: 4–6) for: A) BMI *z* for sex and age B) BMI, kg m^{-2}, ≥pc 85 vs. <pc 85 for sex and age	Beta by linear regression, and OR by logistic regression, models adjusted for sex, gestational age, age, socioeconomic status and mother's: height, BMI and age	Beta, (1A): 0.58 (0.42; 0.74) OR, (1B): 2.23 (1.12–4.46) OR, (2B): 1.38 (0.80–2.39)	Medium

Table 2 *Continued*

Study	*n* subjects* (% boys†), birth year	Exposure, age	Time exposure outcome	Outcome, age	Analysis	Association‡	Quality
Chomtho (2008) (50) London, UK	150–208 (45% boys), birth year not reported	Weight change per SD *z* for sex, gestational age and age, between age: (1) 0 and 3 weeks (2) 3 and 6 weeks (3) 6 weeks and 3 months (4) 0 and 3 months (5) 3 and 6 months (6) 6 months and 1 year Mean ages were all within ±0.2 units	(1) 11.0–11.6 years (2) 11.1–11.7 years (3) 10.9–11.5 years (4) 10.9–11.5 years (5) 10.6–11.2 years (6) 10.1–10.7 years	*Z* of BMI, fat mass index (FMI)§, and waist circumference, for sex and age, at mean age 11.1 years (SD: 3.7) in boys and 11.7 years (SD: 3.9) in girls	Beta by linear regression, adjusted or sex, birth weight, parents' BMI, social class, ethnicity, puberty, physical activity	Beta: (1) BMI, 0.13 (-0.18; 0.44); FMI, 0.06 (–0.20; 0.32); waist, 0.27 (0.00; 0.54) (2) BMI, 0.55 (0.02; 1.08); FMI, 0.38 (–0.07; 0.83); waist, 0.61 (0.14; 1.08) (3) BMI, 0.48 (0.11; 0.85); FMI, 0.35 (0.04; 0.66); waist, 0.28 (–0.07; 0.63) (4) BMI, 0.40 (0.18; 0.62); FMI, 0.29 (0.09; 0.49); waist, 0.39 (0.19; 0.59) (5) BMI, 0.38 (0.07; 0.69); FMI, 0.37 (0.10; 0.64); waist, 0.28 (–0.01; 0.57) (6) BMI, 0.03 (-0.30; 0.36); FMI, 0.002 (–0.27; 0.27); waist, -0.09 (–0.38; 0.20)	High
Hui (2008) (18) Hong Kong, China	6075 (53% boys), 1997	Weight change per SD *z* for sex and age between age: (1) 0 and 3 months (range: 2–4) (2) 3 months and 1 year (range: 9–15 months)	(1) 6.8 years (2) 6 years	BMI *z* for sex and age at age 7 years (range: 5.5–8.5)	Beta by linear regression, adjusted for gestational age, baseline weight (at start of growth measurement), and weight gain for both age periods	Beta, (1): boys, 0.52 (0.47; 0.57); girls, 0.47 (0.41; 0.52) Beta, (2): boys, 0.30 (0.24; 0.36); girls, 0.38 (0.31; 0.45)	High
Karaolis-Danckert (2008) (51) Germany	370 (49% boys), 1990	Weight change $z > 0.67$ vs. ≤ 0.67 for sex and age, between age 0 and 2 years	4 years	(A) BMI *z* for sex and age, at age 6 years (B) fat mass, %, at age 6 years	Beta by linear regression, adjusted for gestational age, overweight in mother, mother's pregnancy smoking status, bottle feeding× time, and pair wise interactions between: weight change, overweight in mother, and mother's pregnancy smoking status. A was additionally adjusted for BMI at birth. B was additionally adjusted for sex, % fat mass at 3 months, firstborn status, firstborn× time, season of birth, season of birth× time.	Beta, (A): 1.07 (0.82; 1.32) Beta, (B): 1.71 (0.91; 2.51)	High
Lamb (2010) (52) Denver, USA	1178 (53% boys), 1994–1995	Weight gain, kg $year^{-1}$, between age 0 and mean 0.8 years (range: 0.5–1 year)	5.8 years	BMI, kg m^{-2}, at mean age 6.6 years (range: 2–11.5 years in boys, 2–11.0 years in girls)	Beta by linear mixed-effect model, adjusted for age, age^2, sex, size for gestational age, breastfeeding duration, and *in utero* exposure to diabetes	Beta: 0.33 (0.28; 0.38)	Medium

Table 2 *Continued*

Study	*n* subjects* (% boys†), birth year	Exposure, age	Time exposure outcome	Outcome, age	Analysis	Association‡	Quality
Joglekar (2007) (19) Pune, India	698 (sex proportion not reported), 1994–1996	Per SD *z* change in weight, height, mid-upper arm circumference (MUAC) and subscapular skin-fold, between age: (1) 0 and 6 months (2) 6 months and 1 year (3) 1 and 2 years (4) 2 and 3 years (5) 3 and 4 years	(1) 5.5 years (2) 5 years (3) 4 years (4) 3 years (5) 2 years	Mean kg fat mass, *z*, at age 6 years	Mean SD of kg fat mass, *z*, at age 6 years, per SD *z* growth during previous age intervals. Seemingly unrelated regression	Mean (95% CI), approximated from figure: (1) weight, 0.30 (sign); height, 0.15 (sign); MUAC, 0.12 (sign); skin-fold, 0.08 (ns) (2) weight, 0.40; height, 0.14; MUAC, 0.16; skin-fold, 0.15. All sign (3) weight, 0.42 (sign); height, 0.05 (ns); MUAC, 0.18 (sign); skin-fold, 0.12 (sign) (4) weight, 0.58 (sign); height, 0.08 (ns); MUAC, 0.12 (sign); skin-fold, 0.15 (sign) (5) weight, 0.20 (ns); height, 0.10 (sign); MUAC, 0.15 (sign); skin-fold, 0.10 (sign)	High
Shapiro (1984) (53) Berkeley, USA	170 (49% boys), 1969	Weight gain, kg, low (<pc 15), middle (pc 15 to 85), high (>pc 85), between age: (1) 0 and 6 months (2) 6 months and 1 year	(1) 8.3 years (2) 7.8 years	Sum of skin-folds, mm: triceps, subscapular, suprailiac, chest, at age 8.8 years	Comparison of skin-fold level at 8.8 years in groups of low, middle and high weight gain. ANOVA	Mean (SD): (1): Boys: low, 17.5 (4.2); middle, 19.6 (8.4); high, 23.3 (6.7), ns. Girls: low, 20.6 (6.1); middle, 25.3 (13.8); high, 29.7 (8.1), ns (2): Boys: low, 16.7 (6.0); middle, 20.0 (8.1); high, 22.7 (7.4), ns. Girls: low, 25.0 (13.7); middle, 23.9 (10.0); high, 30.0 (16.7), ns	Medium
Cameron (2003) (22) Soweto-Johannesburg, South Africa	193 (56% boys), birth year not reported	Weight change *z* for age; rapid [+] >0.67, normal [0] ≤0.67, between age 0 and 2 years	7 years	Body size at age 9 years: (A) weight, kg (B) BMI, kg m^{-2} (C) fat mass, kg (D) fat mass, % (E) sum of skin-folds, mm: triceps, biceps, subscapular, suprailiac, thigh, calf (F) waist circumference, cm	Comparison of body size measures at 9 years in weight change groups. *T*-test	Mean (SD): (A): [+], 32.4 (7.1); [0], 28.6 (4.4), $P = 0.000$ (B): [+], 17.5 (3.1); [0], 16.4 (2.5), $P = 0.000$ (C): [+], 9.76 (5.4); [0], 7.3 (3.3), $P = 0.000$ (D): [+], 28.7 (9.1); [0], 25.0 (7.9), $P = 0.01$ (E): [+], 65.4 (23.0); [0], 54.1 (19.1), $P = 0.001$ (F): [+], 59.7 (7.4); [0], 56.6 (5.3), $P = 0.003$	Medium
Wells (2005) (16) Pelotas, Brazil	172 (100% boys), 1993	Weight change *z* in quartiles for sex and age, between age: (1) 0 and 6 months (2) 6 months and 1 year (3) 1 and 4 years	(1) 8.5 years (2) 8 years (3) 5 years	(A) BMI, kg m^{-2}, at age 9 years (B) fat mass/lean $mass^{2.7} \times 10\,000$, at age 9 years	Comparison of body size measures at 9 years in quartiles (Q) of weight change groups. ANOVA	Mean (SD): (1A): Q1, 16.4 (2.6); Q4, 18.0 (3.4), $P = 0.05$ (1B): Q1, 9.3 (4.1); Q4, 9.0 (5.8), $P = 0.96$ (2A): Q1, 17.8 (3.3); Q4, 17.9 (3.4), $P = 0.54$ (2B): Q1, 9.8 (5.5); Q4, 9.0 (3.8), $P = 0.53$ (3A): Q1, 16.1 (2.7); Q4, 18.8 (3.9), $P < 0.0001$ (3B): Q1, 8.1 (3.5); Q4, 10.0 (5.6), $P = 0.005$	Medium

Table 2 *Continued*

Study	*n* subjects* (% boys†), birth year	Exposure, age	Time exposure outcome	Outcome, age	Analysis	Association‡	Quality
Ceelen (2009) (54) Amsterdam, the Netherlands	193 children born after *in vitro* fertilization and 199 spontaneously born children (controls). Results are here reported for controls. Sex proportion not reported. 2003–2006	Weight change *z* in tertiles (T) between age: (1) 0 and 3 months (2) 3 months and 1 year (3) 1 and 3 year	(1) 12.0 years (2) 11.2 years (3) 9.2 years	Sum of skin-folds, mm: biceps, triceps, subscapular and suprailiac, at mean age 12.2 years (SD: 2.6)	Comparison of sum of skin-fold level at 9 years in tertiles of weight change groups	Mean (SD) (1): T1, 39.3 (20.3); T2, 35.1 (16.5); T3, 36.7 (16.3), $P = 0.8$ (2): T1, 33.5 (15.6); T2, 37.5 (20.0); T3, 41.8 (17.2), $P = 0.003$ (3): T1, 31.7 (12.1); T2, 33.3 (14.1); T3, 44.3 (23.9), $P = 0.005$	Medium
Hitze (2010) (55) Kiel, Germany	351 (51% boys), birth year not reported	Weight change *z* for sex and age; rapid [+] (>0.67), normal [0] (–0.67 to 0.67), slow [–] (<–0.67), between age 0 and mean 2.0 years (SD: 0.1)	10.7 years	Body size at median age 12.9 years (pc 25–75: 10.4–15.2) in boys and 12.4 years (pc 25–75: 10.1–14.8) in girls: (A) BMI, kg m^{-2} (B) waist circumference, cm (C) fat mass, % (D) % BMI ≥pc 90 for sex and age	Comparison of body size at 12 years in weight change groups, adjusted for age, and gestational age. ANCOVA for A–C. Chi-squared test for D	Mean (95% CI), *P*-value [+] vs. [–] (A): boys: [+], 21.8 (20.6–23.1); [0], 19.9 (19.1–20.6); [–], 18.2 (17.1–19.4), $P < 0.001$. girls: [+], 20.9 (19.9–22.0); [0], 19.1 (18.4–19.7); [–], 18.3 (17.2–19.5), $P < 0.01$ (B): boys: [+], 76.0 (72.7–79.2); [0], 70.6 (68.6–72.5); [–], 66.5 (63.3–69.6), $P < 0.001$. girls: [+], 70.6 (68.1–73.2); [0], 67.1 (65.6–68.7); [–], 64.6 (61.9–67.3), $P < 0.01$ (C): boys: [+], 20.6 (17.4–23.7); [0], 15.3 (13.4–17.2); [–], 14.4 (11.3–17.5), $P < 0.05$. girls: [+], 24.1 (21.3–26.9); [0], 18.5 (16.8–20.3); [–], 18.1 (15.1–21.1), $P < 0.05$ %, *P*-value Chi-squared (D): boys: [+], 28.9%; [0], 19.0%; [–], 5.0%, $P < 0.05$. girls: [+], 26.2; [0], 11.6; [–], 2.8, $P < 0.01$	Medium
Law (2002) (39) Brompton, UK	346 (47% boys), 1975–1977	Weight change *z* for sex, age and birth weight, between age 0 and 1 year	4 years (1–5 years)	Weight *z* for sex and age at age 2–6 years, closest to the fifth birthday	Correlation coefficient	*r*: 0.50, $P < 0.001$	Medium
Mai (2005) (56) south-east Sweden	74 (sex proportion not reported), all with birth weight ≤1.5 kg, 1987–1988	Weight change *z* for sex and gestational age, between age: (1) 0 and 6 months (2) 0 and 1.5 years	(1) 11.5 years (2) 10.5 years	BMI, kg m^{-2}, at age 12 years	Correlation coefficient	*r*, (1): 0.34, $P < 0.01$ *r*, (2): 0.24, $P < 0.05$	Low

*Number of subjects refers to the number included in the analysis reported on here.
†Proportion boys in the analysis, or if not reported on in the study, in the full study group.
‡Confidence intervals correspond to 95% precision. Results are presented for the most adjusted model.
§Results for trunk FMI showed similar results as for FMI.
BMI, body mass index; IOTF, International Task Force; ns, non-significant; OR, odds ratio; pc, percentile; ref, referent group; RR, relative risk; SD, standard deviation; sign, significant; vs., versus; z, variable standardized into *z* distribution.

We here first summarize results from developed countries. Results from the seven studies from developing countries are reported separately.

Body size

In 19 studies on body size from developed countries, weight (11 studies) and BMI (8 studies) were most commonly used as measures of body size at baseline (Table 1). Weight was the most common measure in children younger than 2 years, whereas BMI was more commonly used in children 2 years or older. BMI was most commonly used as outcome measure of body size (13 studies). Few studies included other baseline measures than weight or BMI, and few included other outcome measures than BMI. No study presented results for various measures of baseline body size such that their strength of associations with subsequent body size could be compared.

Less than 2 years of age

Fifteen studies reported on body size measured before 2 years of age, mainly assessed at age 5–6 months or later. In 11 of these studies, weight was used as the body size measure at baseline (11,26,27,29,30,34–39). Weight at the highest end of the distribution was related to significantly higher subsequent weight (29,37,39) and BMI (11,26,27,35) in seven low- to high-quality studies. In four of these studies, baseline age was 6 months or less (26,29,35,37). No significant association was observed in four studies with a small sample size ($n \leq 216$) (30,34,36,38). In a large high-quality study, each SD higher weight at 1.5 years of age was related to 0.29 SD higher BMI at 7 years of age (35). Two high-quality studies reported on odds ratios for BMI above percentile 95 at 7 years of age (11,27). In one of these studies, there was a modest 1.05-fold increased odds per 100-g weight at 1 year of age (27). The other study showed threefold higher odds for weight above versus below percentile 75 at 8 months of age, which increased to 3.7-fold higher odds for high weight at age 1.5 years (11).

Body mass index was measured at baseline in five studies (24,25,33,37,38), and all (24,25,33,37), except one low-quality study (38), showed a significant positive association with subsequent BMI. Two studies reported on height measured at 1 year of age, and none found a significant association with subsequent BMI (34,38).

Two years or older

We identified seven studies of medium or low quality in which body size at baseline had been measured as of 2 years of age (23,24,26,31,32,37,40). Five of these studies reported on the association between BMI measured at two ages (23,24,31,32,37), and all showed a positive association, although it was non-significant in one study (23). One of the studies with significant results showed that, at 2.5 years of age, overweight versus normal or low weight on international growth charts (12) was related to an odds ratio of 12.4 for overweight, and 25.5 for obesity, at 5 years of age (24).

Weight at 2–4 years of age was in two studies significantly positively related to weight or BMI at 5–6 years of age (26,37).

Growth

All 25 studies from developed countries had assessed growth as weight gain, either in absolute level or as change in z-score (Table 2). Ong *et al*. defined rapid weight gain as a change in z-score higher than 0.67, which represents the width between two percentile bands on growth charts with percentiles 2, 9, 25, 50, 75, 91 and 98 (10). This definition has been used in several later studies, including five in this review (11,22,41,51,55). In addition to weight increase, two studies also reported on height increase (34,40). Similar to studies that reported on body size at baseline, studies on growth most commonly reported on BMI as outcome measure (17 studies). Fat mass percent or index had been measured at outcome in eight studies, and weight in four studies. Age at which growth had been measured, and follow-up time, differed widely between studies. The age range was between 0–3 weeks and 1–4 years. A number of studies reported on growth between the exact ages 0–1 years and 0–2 years, for which we present the results separately. We also summarize results for growth measured at any period before 1 year of age, and for growth spanning over age 2 years or later.

Any period before 1 year of age

In total 14 studies reported on weight gain at various ages up to 1 year of age (27,35,36,40,42–44,48–50,52–54,56), i.e. not counting studies assessing growth between the exact time period of 0–1 year. Nine studies included infants younger than 6 months of age. Five of these studies – four of high quality – showed that high weight gain or change in z-score measured between ages 0–6 weeks and 0–6 months were related to significantly higher subsequent BMI (27,35,48,49,56), weight (48) or fat mass (48). In three small studies ($n \leq 224$) of medium or low quality, the association was non-significant for growth at 0–3 or 0–6 months (42,53,54). The ninth study reported on the association between weight change z-score and subsequent BMI, fat mass index and waist circumference (50). No significant association was found for weight change between 0 and 3 weeks of age, but growth in later age periods up to 6 months of age was significantly positively associated with BMI, and fat mass index or waist circumference. In high-quality studies, the effect size for one SD change in weight z-score at ages ranging from 0–3 weeks to 3–6 months were calculated to 0.13–0.55 SD higher BMI at age 7–12 years (35,48,50). One high-quality study reported odds ratios and showed that each 100-g weight gain between 0 and 4 months of age was associated with 1.4-fold higher odds of having a BMI above percentile 95 at 7 years of age (27).

Ten studies of medium or high quality that reported on weight gain in grams or z-score change before 1 year of age included growth after, or crossing over, 6 months of age (36,40,43,44,48–50,52–54). Five of these studies showed significant associations with subsequent body size (40,48,49,52,54), three showed significant results in boys only (36,43,44) and two studies showed no significant association (50,53).

Birth to 1 year

Five low- to high-quality studies reported absolute weight gain or change in z-score between 0 and 1 year of age, and all showed a significant positive association with subsequent BMI (11,34,38,45), or weight (39). In one study the weight gain/birth weight ratio was a stronger predictor of subsequent BMI than was height gain (34). One high-quality study reported on odds ratios and it showed that high weight change ($z > 0.67$) between 0 and 1 year of age was compared to normal weight change ($-0.67 \leq z \leq 0.67$) related to 2.2-fold higher odds of having a BMI above the 95th percentile at 7 years of age (11).

Birth to 2 years

In six low- to high-quality studies, weight gain had been measured at age 0–2 years, and all studies showed a significant positive association with subsequent body size (10,41,46,47,51,55). In four of these studies, rapid weight gain was defined as a change in weight z-score higher than 0.67 (10,41,51,55). Karaolis-Danckert *et al.* showed that such rapid weight gain, compared to change in weight z-score ≤ 0.67, was related to 1.1 SD higher BMI and 1.7 units higher fat mass percentage at age 6 years (51), and it was related to sixfold higher odds of BMI higher than 25 kg m^{-2} on international growth charts (12) at age 7 years (41). Two other studies showed that rapid weight gain was related to higher levels of a wide range of body size measures in later life: weight, BMI, fat mass (absolute and percent), skin-folds and waist circumference (10,55).

After 2 years of age

Three studies reported on weight change z-score between approximately 1–3 years (54) and 1–4 years of age (40,49). These studies showed that growth was significantly positively related to BMI (47), fat mass percent (40) or skin-folds (54), at 7–12.2 years of age. One of the studies included a high proportion of children born small for gestational age, and it showed that, compared to the lowest quartile, weight change in the top quartile was related to having six units higher fat mass percentage at 7.3 years of age (40). In these three studies that assessed growth before and after the second birthday, it remains unclear which growth period, before or after 2 years of age, had the strongest relationship to body size at a later age.

Body size or growth in developing countries

Seven studies originated from developing countries. These studies were published in 2002 and later, and they were evaluated as medium- or high-quality studies. In two studies from Chile (17) and India (19), various measures of body size measured at 6 months of age and later were significantly positively related to BMI at 5 years (17), and fat mass at 6 years of age (19). The Indian study also reported on growth in weight, height, mid-upper arm circumference and subscapular skin-folds at various ages ranging from 0–6 months to 3–4 years (19). A significant positive association with fat mass was generally found for all baseline measures and ages, in particular for weight. In four other studies, absolute weight gain or z-score change (18,21,22), or change in BMI z-score (20), in various periods between 0 and 2 years of age, were significantly positively associated with BMI (18,20–22) and other measures of body size (22) at 5–13 years of age. Another study, from Brazil, showed that high change in weight z-score between 1 and 4 years of age, but not before 1 year of age, was related to high BMI and fat mass index at 9 years of age (16).

Discussion

The results of this review showed that large body size as of 5–6 months of age, and fast weight gain before 2 years of age, are related to large body size at age 5–13 years. There was consistent evidence of an association between fast weight gain at 0–1 year and 0–2 years of age with large subsequent body size. The association was also indicated for growth in infants younger than 6 months of age. The results in this review were mainly based on studies from developed Western countries.

A weakness of this review is that included studies differed largely in their design and methods, such as in children's age and follow-up time, body size measurements and statistical analysis. Such heterogeneity between studies makes comparisons difficult, and a meta-analysis of data would include only a minority of the studies. We tried to increase comparability between studies by reporting results separately by age and baseline body size measure, and by exemplifying effect size only from results derived from regression analysis. We further increased comparability by restricting outcome age to a maximum of 13 years. It may be argued that this approach reduced the importance of our results because an association with overweight at primary school age may not persist into adulthood. However, the relationship between obesity in infancy and childhood and obesity in adulthood has been well documented (4–6), and therefore we limited our inclusion criteria for increasing homogeneity between studies. Despite these actions to increase comparability between studies, it should be noted that follow-up time differed between studies, which also complicates the comparison of results. It should also be noted that, as in any other review, there is a chance that our results were influenced by publication bias. Studies with significant results may be overrepresented because those are more frequently published than are non-significant results (57).

Findings in our review were based on data from 18 studies included in previous reviews on the topic (4–6) and on 25 additional studies. Conclusions in previous reviews of a positive association between body size and growth in infancy and childhood and subsequent body size were supported by the large number of recent studies in this review. In our review, we investigated the association by age at baseline in more detail than has been done previously, and we found indications that body size and growth already before 6 months of age is related to size at primary school age. Although these findings were fairly robust among studies of body size and among high-quality studies of growth, further studies are needed to specify the starting age in infancy at which body size is linked to size in later childhood, and to clarify if certain age ranges of growth are more strongly related to body size several years later. It also remains to be clarified if there is a threshold of body size and growth at which risk of obesity increases steeply. Our and previous reviews showed consistency in data between Western countries. We found indications that the results also confer to developing countries, but these findings were derived from only seven studies originating from these countries.

In a recent review by Monasta *et al.* on obesity risk factors before 5 years of age, large body size or fast growth was identified as one of five factors that in higher-quality reviews have been related to subsequent obesity (7). The other four risk factors were maternal smoking, no breastfeeding or early cessation of breastfeeding, short sleep duration and television viewing. Hypothetically, modification of these risk factors could prevent early development of obesity. Even so, evidence is sparse on the effect of obesity prevention in the youngest children. This is shown in another recent review by Monasta *et al.* who summarize results from seven randomized controlled trials on obesity prevention in children younger than 5 years of age (58). In these trials of physical activity and/or healthy nutrition or breastfeeding, little evidence was found for an effect on obesity in the child. However, several methodological limits of the studies were raised in the review. Taking it all together, it is clear that large body size and fast growth in the first few years of life are related to obesity in later life, but it is unclear if and how they can be modified. Early obesity development might be preventable if signs are detected early and the right care is provided, but further knowledge about efficient and safe actions to modify weight and growth in the first years of life are needed.

Conflicts of Interest Statement

No conflict of interest was declared.

Acknowledgements

We thank Monique L'Hoir, Senior Researcher at the Netherlands Organization for Applied Scientific Research into Quality of Life, Leiden, the Netherlands, and Derek-Ian Blok, Managing Director of Public Health at the Government Administration Industry, Aruba, Netherlands Antilles, for productive discussions about the study in its initial phase.

References

1. Barker DJ. The origins of the developmental origins theory. *J Intern Med* 2007; **261**: 412–417.
2. de Boo HA, Harding JE. The developmental origins of adult disease (Barker) hypothesis. *Aust N Z J Obstet Gynaecol* 2006; **46**: 4–14.
3. Kiess W, Petzold S, Topfer M, Garten A, Bluher S, Kapellen T, Korner A, Kratzsch J. Adipocytes and adipose tissue. *Best Pract Res Clin Endocrinol Metab* 2008; **22**: 135–153.
4. Baird J, Fisher D, Lucas P, Kleijnen J, Roberts H, Law C. Being big or growing fast: systematic review of size and growth in infancy and later obesity. *BMJ* 2005; **331**: 929.
5. Ong KK, Loos RJ. Rapid infancy weight gain and subsequent obesity: systematic reviews and hopeful suggestions. *Acta Paediatr* 2006; **95**: 904–908.
6. Singh AS, Mulder C, Twisk JW, van Mechelen W, Chinapaw MJ. Tracking of childhood overweight into adulthood: a systematic review of the literature. *Obes Rev* 2008; **9**: 474–488.
7. Monasta L, Batty GD, Cattaneo A, Lutje V, Ronfani L, van Lenthe FJ, Brug J. Early-life determinants of overweight and obesity: a review of systematic reviews. *Obes Rev* 2010; **11**: 695–708.
8. Greenhalgh T, Peacock R. Effectiveness and efficiency of search methods in systematic reviews of complex evidence: audit of primary sources. *BMJ* 2005; **331**: 1064–1065.
9. Whitaker RC, Wright JA, Pepe MS, Seidel KD, Dietz WH. Predicting obesity in young adulthood from childhood and parental obesity. *N Engl J Med* 1997; **337**: 869–873.
10. Ong KK, Ahmed ML, Emmett PM, Preece MA, Dunger DB. Association between postnatal catch-up growth and obesity in childhood: prospective cohort study. *BMJ* 2000; **320**: 967–971.
11. Reilly JJ, Armstrong J, Dorosty AR, Emmett PM, Ness A, Rogers I, Steer C, Sherriff A. Early life risk factors for obesity in childhood: cohort study. *BMJ* 2005; **330**: 1357.
12. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ* 2000; **320**: 1240–1243.
13. Centre for Reviews and Dissemination. *Systematic Reviews: CRD's Guidance for Undertaking Reviews in Health Care*. University of York: York; 2009.
14. Baird J, Lucas P, Kleijnen J, Fisher D, Roberts H, Law C. Defining optimal infant growth for lifetime health: a systematic review of lay and scientific literature. 2005. URL http://www.mrc.soton.ac.uk/index.asp?page=176 (accessed 15 March 2010).
15. International Monetary Fund. World Economic Outlook Report, October 2009. List of Developed and Developing Coun-

tries. [WWW document]. URL http://www.imf.org/external/pubs/ft/weo/2009/02/weodata/groups.htm/en-en/# (accessed 31 May 2010).
16. Wells JC, Hallal PC, Wright A, Singhal A, Victora CG. Fetal, infant and childhood growth: relationships with body composition in Brazilian boys aged 9 years. *Int J Obes (Lond)* 2005; **29**: 1192–1198.
17. Kain J, Corvalan C, Lera L, Galvan M, Uauy R. Accelerated growth in early life and obesity in preschool Chilean children. *Obesity (Silver Spring)* 2009; **17**: 1603–1608.
18. Hui LL, Schooling CM, Leung SS, Mak KH, Ho LM, Lam TH, Leung GM. Birth weight, infant growth, and childhood body mass index: Hong Kong's children of 1997 birth cohort. *Arch Pediatr Adolesc Med* 2008; **162**: 212–218.
19. Joglekar CV, Fall CH, Deshpande VU, Joshi N, Bhalerao A, Solat V, Deokar TM, Chougule SD, Leary SD, Osmond C, Yajnik CS. 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.
20. Jones-Smith JC, Fernald LC, Neufeld LM. Birth size and accelerated growth during infancy are associated with increased odds of childhood overweight in Mexican children. *J Am Diet Assoc* 2007; **107**: 2061–2069.
21. Stettler N, Bovet P, Shamlaye H, Zemel BS, Stallings VA, Paccaud F. Prevalence and risk factors for overweight and obesity in children from Seychelles, a country in rapid transition: the importance of early growth. *Int J Obes Relat Metab Disord* 2002; **26**: 214–219.
22. Cameron N, Pettifor J, De Wet T, Norris S. The relationship of rapid weight gain in infancy to obesity and skeletal maturity in childhood. *Obes Res* 2003; **11**: 457–460.
23. Nader PR, O'Brien M, Houts R, Bradley R, Belsky J, Crosnoe R, Friedman S, Mei Z, Susman EJ. Identifying risk for obesity in early childhood. *Pediatrics* 2006; **118**: e594–e601.
24. Huus K, Ludvigsson JF, Enskar K, Ludvigsson J. Risk factors in childhood obesity-findings from the All Babies In Southeast Sweden (ABIS) cohort. *Acta Paediatr* 2007; **96**: 1321–1325.
25. Scholtens S, Gehring U, Brunekreef B, Smit HA, de Jongste JC, Kerkhof M, Gerritsen J, Wijga AH. Breastfeeding, weight gain in infancy, and overweight at seven years of age: the prevention and incidence of asthma and mite allergy birth cohort study. *Am J Epidemiol* 2007; **165**: 919–926.
26. Touchette E, Petit D, Tremblay RE, Boivin M, Falissard B, Genolini C, Montplaisir JY. Associations between sleep duration patterns and overweight/obesity at age 6. *Sleep* 2008; **31**: 1507–1514.
27. Stettler N, Zemel BS, Kumanyika S, Stallings VA. Infant weight gain and childhood overweight status in a multicenter, cohort study. *Pediatrics* 2002; **109**: 194–199.
28. Johnston FE, Mack RW. Obesity in urban black adolescents of high and low relative weight at 1 year of age. *Am J Dis Child* 1978; **132**: 862–864.
29. Poskitt EM, Cole TJ. Do fat babies stay fat? *Br Med J* 1977; **1**: 7–9.
30. Wilkinson PW, Parkin JM, Pearlson J, Philips PR, Sykes P. Obesity in childhood: a community study in Newcastle upon Tyne. *Lancet* 1977; **1**: 350–352.
31. Magarey AM, Daniels LA, Boulton TJ, Cockington RA. Predicting obesity in early adulthood from childhood and parental obesity. *Int J Obes Relat Metab Disord* 2003; **27**: 505–513.
32. Vanhala M, Korpelainen R, Tapanainen P, Kaikkonen K, Kaikkonen H, Saukkonen T, Keinänen-Kiukaanniemi S. Lifestyle risk factors for obesity in 7-year-old children. *Obes Res Clin Pract* 2009; **3**: 99–107.
33. Fuentes RM, Notkola IL, Shemeikka S, Tuomilehto J, Nissinen A. Tracking of body mass index during childhood: a 15-year prospective population-based family study in eastern Finland. *Int J Obes Relat Metab Disord* 2003; **27**: 716–721.
34. Gunnarsdottir I, Thorsdottir I. Relationship between growth and feeding in infancy and body mass index at the age of 6 years. *Int J Obes Relat Metab Disord* 2003; **27**: 1523–1527.
35. Kinra S, Baumer JH, Davey Smith G. Early growth and childhood obesity: a historical cohort study. *Arch Dis Child* 2005; **90**: 1122–1127.
36. Gale CR, Javaid MK, Robinson SM, Law CM, Godfrey KM, Cooper C. Maternal size in pregnancy and body composition in children. *J Clin Endocrinol Metab* 2007; **92**: 3904–3911.
37. Dine MS, Gartside PS, Glueck CJ, Rheines L, Greene G, Khoury P. Where do the heaviest children come from? A prospective study of white children from birth to 5 years of age. *Pediatrics* 1979; **63**: 1–7.
38. Vogels N, Posthumus DL, Mariman EC, Bouwman F, Kester AD, Rump P, Hornstra G, Westerterp-Plantenga MS. Determinants of overweight in a cohort of Dutch children. *Am J Clin Nutr* 2006; **84**: 717–724.
39. Law CM, Shiell AW, Newsome CA, Syddall HE, Shinebourne EA, Fayers PM, Martyn CN, de Swiet M. Fetal, infant, and childhood growth and adult blood pressure: a longitudinal study from birth to 22 years of age. *Circulation* 2002; **105**: 1088–1092.
40. Blair NJ, Thompson JM, Black PN, Becroft DM, Clark PM, Han DY, Robinson E, Waldie KE, Wild CJ, Mitchell EA. Risk factors for obesity in 7-year-old European children: the Auckland Birthweight Collaborative Study. *Arch Dis Child* 2007; **92**: 866–871.
41. Karaolis-Danckert N, Buyken AE, Bolzenius K, Perim de Faria C, Lentze MJ, Kroke A. Rapid growth among term children whose birth weight was appropriate for gestational age has a longer lasting effect on body fat percentage than on body mass index. *Am J Clin Nutr* 2006; **84**: 1449–1455.
42. Eid EE. Follow-up study of physical growth of children who had excessive weight gain in first six months of life. *Br Med J* 1970; **2**: 74–76.
43. Mellbin T, Vuille JC. Physical development at 7 years of age in relation to velocity of weight gain in infancy with special reference to incidence of overweight. *Br J Prev Soc Med* 1973; **27**: 225–235.
44. Mellbin T, Vuille JC. Relationship of weight gain in infancy to subcutaneous fat and relative weight at 10 1/2 years of age. *Br J Prev Soc Med* 1976; **30**: 239–243.
45. von Kries R, Toschke AM, Koletzko B, Slikker W Jr. Maternal smoking during pregnancy and childhood obesity. *Am J Epidemiol* 2002; **156**: 954–961.
46. Toschke AM, Grote V, Koletzko B, von Kries R. Identifying children at high risk for overweight at school entry by weight gain during the first 2 years. *Arch Pediatr Adolesc Med* 2004; **158**: 449–452.
47. Beyerlein A, Toschke AM, von Kries R. Risk factors for childhood overweight: shift of the mean body mass index and shift of the upper percentiles: results from a cross-sectional study. *Int J Obes (Lond)* 2010; **34**: 642–648.
48. Ong KK, Emmett P, Northstone K, Golding J, Rogers I, Ness AR, Wells JC, Dunger DB. Infancy weight gain predicts childhood body fat and age at menarche in girls. *J Clin Endocrinol Metab* 2009; **94**: 1527–1532.
49. Hemachandra AH, Howards PP, Furth SL, Klebanoff MA. Birth weight, postnatal growth, and risk for high blood pressure at

7 years of age: results from the Collaborative Perinatal Project. *Pediatrics* 2007; **119**: e1264–e1270.
50. Chomtho S, Wells JC, Williams JE, Davies PS, Lucas A, Fewtrell MS. Infant growth and later body composition: evidence from the 4-component model. *Am J Clin Nutr* 2008; **87**: 1776–1784.
51. Karaolis-Danckert N, Buyken AE, Kulig M, Kroke A, Forster J, Kamin W, Schuster A, Hornberg C, Keil T, Bergmann RL, Wahn U, Lau S. How pre- and postnatal risk factors modify the effect of rapid weight gain in infancy and early childhood on subsequent fat mass development: results from the Multicenter Allergy Study 90. *Am J Clin Nutr* 2008; **87**: 1356–1364.
52. Lamb MM, Dabelea D, Yin X, Ogden LG, Klingensmith GJ, Rewers M, Norris JM. Early-life predictors of higher body mass index in healthy children. *Ann Nutr Metab* 2010; **56**: 16–22.
53. Shapiro LR, Crawford PB, Clark MJ, Pearson DL, Raz J, Huenemann RL. Obesity prognosis: a longitudinal study of children from the age of 6 months to 9 years. *Am J Public Health* 1984; **74**: 968–972.
54. Ceelen M, van Weissenbruch MM, Prein J, Smit JJ, Vermeiden JP, Spreeuwenberg M, van Leeuwen FE, Delemarre-van de Waal HA. Growth during infancy and early childhood in relation to blood pressure and body fat measures at age 8-18 years of IVF children and spontaneously conceived controls born to subfertile parents. *Hum Reprod* 2009; **24**: 2788–2795.
55. Hitze B, Bosy-Westphal A, Plachta-Danielzik S, Bielfeldt F, Hermanussen M, Muller MJ. Long-term effects of rapid weight gain in children, adolescents and young adults with appropriate birth weight for gestational age: the kiel obesity prevention study. *Acta Paediatr* 2010; **99**: 256–262.
56. Mai XM, Gaddlin PO, Nilsson L, Leijon I. Early rapid weight gain and current overweight in relation to asthma in adolescents born with very low birth weight. *Pediatr Allergy Immunol* 2005; **16**: 380–385.
57. Egger M, Smith GD. Bias in location and selection of studies. *BMJ* 1998; **316**: 61–66.
58. Monasta L, Batty GD, Macaluso A, Ronfani L, Lutje V, Bavcar A, van Lenthe FJ, Brug J, Cattaneo A. Interventions for the prevention of overweight and obesity in preschool children: a systematic review of randomized controlled trials. *Obes Rev* 2010; doi: 10.1111/j.1467-789X.2010.00774.x.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Quality evaluation of cohort studies; Quality evaluation of case–control studies.

Please note: Wiley-Blackwell is not responsible for the content or functionality of any supporting materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.