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ORIGINAL ARTICLE

Birth order progressively affects childhood height

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Summary

Background There is evidence suggesting that first-born children and adults are anthropometrically different to later-borns. Thus, we aimed to assess whether birth order was associated with changes in growth and metabolism in childhood.

Methods We studied 312 healthy prepubertal children: 157 first-borns and 155 later-borns. Children were aged 3–10 years, born 37–41 weeks gestation, and of birth weight appropriate-for-gestational-age. Clinical assessments included measurement of children's height, weight, fasting lipid and hormonal profiles and DEXA-derived body composition.

Results First-borns were taller than later-borns ($P < 0{\cdot}0001$), even when adjusted for parents' heights (0·31 *vs* 0·03 SDS; $P = 0{\cdot}001$). There was an incremental height decrease with increasing birth order, so that first-borns were taller than second-borns ($P < 0{\cdot}001$), who were in turn taller than third-borns ($P = 0{\cdot}007$). Further, among sibling pairs both height SDS ($P = 0{\cdot}009$) and adjusted height SDS ($P < 0{\cdot}0001$) were lower in second- *vs* first-born children. Consistent with differences in stature, first- ($P = 0{\cdot}043$) and second-borns ($P = 0{\cdot}003$) had higher IGF-I concentrations than third-borns. Both first- ($P < 0{\cdot}001$) and second-borns ($P = 0{\cdot}004$) also had reduced abdominal adiposity (lower android fat to gynoid fat ratio) when compared with third-borns. Other parameters of adiposity and blood lipids were unaffected by birth order.

Conclusions First-borns were taller than later-born children, with an incremental height reduction from first to third birth order. These differences were present after correction for genetic height, and associated to some extent with alterations in plasma IGF-I. Our findings strengthen the evidence that birth order is associated with phenotypic changes in childhood.

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Introduction

There is a trend towards smaller families with an increasing number of couples having fewer children. As a result, there has been a steady increase in the population of first-born children relative to later-borns, and first-borns now represent over 60% of all births in the developed world.[1,2] The trend towards smaller families began in the mid 20th century, but over the past two decades more couples are choosing to have only one or two children.[2] Fertility rates have consequently fallen to a mean of 1·56 live births per woman in Europe, reflecting the trend towards smaller families as well as an overall reduction in birth rates.[1] Changes in family size have occurred for a number of reasons, such as increased availability of contraception, economic pressures and advanced maternal age at first childbirth.[2] This is notwithstanding the impact of official national policies, such as the "one child" policy in China.

There is evidence that birth order affects offspring phenotype. Taller stature in first- compared with later-borns has been previously described in children,[3–5] adolescents[6] and adults.[7–10] However, all of these studies were conducted in populations including subjects from a broad range of socioeconomic groups[3–5] and/or children's heights were not adjusted for parental height[3]. Nonetheless, birth order is known to affect offspring disease risk. First-born adults are at higher risk of obesity than later-borns.[6,8] Compared with later-borns, first-born children were also shown to have reduced insulin sensitivity,[11] higher blood pressure[11,12] and a greater risk of developing type 1 diabetes.[13] One adult study has described a less favourable lipid profile in first-borns,[10] but there are no data on the potential effects of birth order on blood lipids in childhood. Thus, we aimed to determine whether first-born children would have different height, body composition, metabolism and hormonal profiles compared with later-born children.

Methods

Ethics approval

Ethics approval for this study was provided by the Northern Y Regional Ethics Committee (Ministry of Health, New Zealand). Written informed consent was obtained from parents or guard-

ians, as well as verbal or written consent from each child as was appropriate to their age.

Subjects

We undertook a large project examining the effects of parental and prenatal factors in the offspring. From this larger project, we have examined the impact of conception with ovarian stimulation drugs on the growth and metabolism of children.[14] Children conceived after ovarian stimulation were asked to invite family friends and school friends who were naturally conceived to participate in the study as controls,[14] so that these controls were recruited randomly by study participants. Thus, in this current study we assessed only the entire naturally conceived cohort that was recruited from this larger project.

Only healthy, developmentally normal, prepubertal children aged 3–10 years, born full-term (37–41 weeks gestation) were studied. All children were of New Zealand European ethnicity, naturally conceived, born of singleton pregnancies and of birth weight appropriate-for-gestational-age [birthweight >-2 and <2 standard deviation scores (SDS)]. Exclusion criteria also included signs of puberty (Tanner stage 2 breast development in girls and testicular volume >3 ml in boys or evidence of adrenarche), receiving medication that could affect insulin sensitivity or growth, and having a first degree relative with diabetes. Children were also excluded if born to mothers with gestational diabetes, pre-eclampsia, gestational or pre-existing hypertension, chronic illnesses or maternal drug use (including tobacco) during pregnancy. All participants were of higher socio-economic status according to their residential address and the "decile score" of the school they attended.[15] A decile score reflects the socio-economic status of the school communities, where decile 1 indicates lowest and 10 highest socio-economic status.[15] All participants in the study were of decile 9 or 10 socio-economic status.

Study parameters

All clinical assessments were carried out at the Maurice & Agnes Paykel Clinical Research Unit (Liggins Institute, University of Auckland). Standing height was measured using a Harpenden stadiometer. Each child was measured between 07·30 and 08·00 AM by the same paediatrician, using standard techniques for accurate height measurement as per Schilg *et al.*[16] Children's weight and body composition were assessed using dual-energy X-ray absorptiometry (DEXA Lunar Prodigy 2000; General Electric, Madison, WI, USA). Apart from the total body fat percentage, other DEXA-derived parameter of interest was abdominal adiposity, which was expressed as the android fat to gynoid fat ratio. This ratio is provided by the manufacturer's software, based on an automated sectioning of specific areas of the body.[17] A number of studies in children have shown that proportionally greater adiposity in the upper body (i.e. android fat) is associated with an increased risk of adverse metabolic outcomes.[18] Each child had a bone age X-ray to determine biological maturity, which was blindly assessed by a single paediatric endocrinologist using pre-established standards.[19] Maternal and paternal height and weight were measured, and body mass index (BMI) was calculated. Maternal obstetric history was also recorded to clarify parity and identify the birth order of each subject.

Children's birth weight, height, BMI and parental heights were transformed into SDS.[20] Mid-parental height SDS (MPHSDS) was calculated for each child.[21] Children's height SDS were then individually adjusted for their genetic potential (parents' heights), using the formula: child's height SDS minus MPHSDS. Parents' BMI were transformed into SDS, and the mean parental BMISDS (MPBMISDS) was calculated for each child.[22] The SDS system expresses the extent of the deviation of a given value from the standard population mean. Each SDS is calculated as the individual value minus the mean value for the reference population (given gender and age), divided by the standard deviation of the reference population. Thus, the mean reference point is zero.[20]

Following an overnight fast, morning blood samples were drawn to measure serum glucose, insulin, total cholesterol, high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), triglycerides, insulin-like growth factor-I (IGF-I), IGF-II, IGF binding protein-3 (IGFBP-3). An insulin resistance score (HOMA-IR) was also computed using fasting glucose and insulin concentrations.[23]

Assays

Glucose concentrations were measured on a Hitachi 902 autoanalyser (Hitachi High Technologies Corporation, Tokyo, Japan) by enzymatic colorimetric assay (Roche, Mannheim, Germany), with an interassay coefficient of variation (CV) of 2·1%. Insulin concentrations were measured using an Abbott AxSYM system (Abbott Laboratories, Abbott Park, IL, USA) by microparticle enzyme immunoassay, with a CV of 5·7%. Total cholesterol, HDL-C, and LDL-C concentrations were measured using a Hitachi 902 autoanalyser, with CV of 8·9%, 11·4, and 10·1 respectively. Commercially available ELISA kits E20, E30, E03A, E07 and E09 (Mediagnost, Reutlingen, Germany) were used for quantitative determination of serum IGF-I, IGF-II, IGFBP-3, leptin and adiponectin respectively; assay sensitivities were 0·09, 0·02, 0·1, 1·0 and 0·6 ng/ml, with CV of 3·1, 5·0, 9·6, 6·7 and 3·0% respectively.

Statistical analysis

Mean age was compared using one-way ANOVA and sex ratio with Fisher's exact test, both in Minitab v.16 (Pennsylvania State University, State College, PA, USA). Children were separated into two groups according to their birth order: first-borns and later-borns. Comparisons between birth order groups were carried out using linear mixed models in SAS v.9·2 (SAS Institute, Cary, NC, USA). All models accounted for important confounding factors, mainly gender, birth weight SDS, gestational age and maternal age. All models included family identification number as a random factor, to account for the clustering of siblings.

Other factors were controlled for as required, depending on the outcome response of interest: for lipids, hormones and outcomes associated with glucose homeostasis – age and BMISDS were included; for anthropometric data – age and the appropriate parental factor (i.e. MPBMISDS or MPHSDS); and for blood pressure parameters – height and total body fat percentage. For a smaller number of outcomes, data were re-analysed with subjects split into three groups according to birth order (first-, second- and third-borns).

The interaction effect between birth order and gender was tested in all models. Outcomes were only assessed separately for boys and girls when there was an indication of a differential response to birth order between genders. In addition, main outcomes were analysed separately for all sibling pairs of first- and second-born children. Where appropriate, data were log-transformed to approximate a normal distribution. Data are provided as means and 95% confidence intervals adjusted for the confounders in multivariate models (back-transformed were appropriate).

Results

In all, 343 eligible children volunteered to participate, but 31 were subsequently excluded: 22 were born prematurely or small-for-gestational-age, five were pubertal, three children had mothers with gestational diabetes or glucose intolerance, and one child was on medication known to influence growth. Thus, a total of 312 children took part in the study: 157 first-borns (50%) and 155 later-borns (50%) (Table 1; Fig. 1). Later-borns were comprised of 119 second-born and 36 third-born children (Fig. 1). Sixty-eight children were sibling pairs ($n = 136$) and 12 families had three siblings who participated in the study ($n = 36$).

The characteristics of the study population are outlined in Table 1. First-borns were of similar gestational age, but of lower birth weight than later-borns with a mean birth weight difference of 120 g ($P = 0{\cdot}011$; Table 1). First-borns were older than later-borns ($P < 0{\cdot}0001$; Table 1), while second-born children were older than third-borns ($P < 0{\cdot}05$; Table 2).

First-borns were taller than later-borns ($P < 0{\cdot}0001$), even when adjusted for parents' heights ($P < 0{\cdot}0001$; Table 1). In fact, there was an incremental height decrease from first- to third-borns. Thus, first-borns were taller than second-borns ($P < 0{\cdot}001$),

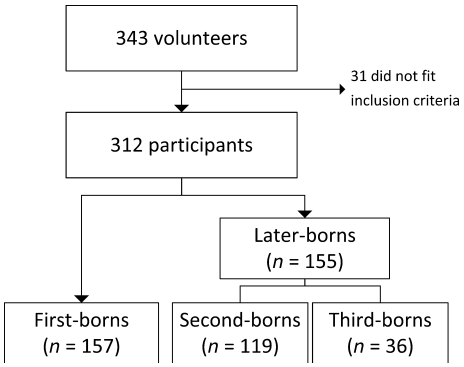

Fig. 1 Summary of the study's recruitment process.

Table 1. Baseline characteristics and fasting serum endocrine and metabolic parameters in first-born *vs* later-born children. Age and MPHSDS data are mean ± SD; other data are means and 95% confidence intervals adjusted for other confounding factors (including birth parameters and age) in the multivariate models. Abdominal adiposity is the android fat to gynoid fat ratio

	First-borns	Later-borns	*P*-value
n	157	155	
Sex ratio (boys)	54%	54%	
Age (years)	8·1 ± 2·1	6·5 ± 1·9	**<0·0001**
Chronological age – bone age (years)	−0·19 ± 0·93	−0·11 ± 0·69	0·49
Gestation (weeks)	39·8 (39·6–40·0)	39·6 (39·4–39·8)	0·13
Birth weight (kg)	3·48 (3·41–3·55)	3·60 (3·53–3·67)	**0·011**
HtSDS	1·08 (0·93–1·23)	0·67 (0·52–0·82)	**<0·0001**
MPHSDS	0·77 ± 0·72	0·89 ± 0·77	0·17
HtSDS–MPHSDS	0·42 (0·29–0·55)	0·13 (0·00–0·26)	**<0·0001**
BMISDS	−0·09 (−0·27–0·08)	−0·05 (−0·23–0·13)	0·84
Abdominal adiposity	0·59 (0·56–0·62)	0·63 (0·60–0·66)	0·11
Total body fat (%)	17·9 (16·8–18·9)	16·6 (16·5–18·7)	0·65
Total cholesterol (mmol/l)	4·33 (4·21–4·46)	4·41 (4·28–4·53)	0·56
LDL-C (mmol/l)	2·47 (2·36–2·58)	2·56 (2·44–2·67)	0·35
HDL-C (mmol/l)	1·37 (1·32–1·43)	1·39 (1·33–1·45)	0·64
Triglycerides (mmol/l)	0·73 (0·69–0·78)	0·76 (0·71–0·81)	0·88
Insulin sensitivity (HOMA-IR)	1·22 (1·10–1·35)	1·24 (1·12–1·36)	0·79
IGF-I (μg/l)	109 (101–118)	112 (103–120)	0·67
IGF-II (μg/l)	739 (723–755)	747 (731–763)	0·51
IGFBP-3 (μg/l)	2554 (2401–2707)	2635 (2478–2792)	0·41

Statistically significant results ($P < 0.05$) are shown in bold.

Table 2. Baseline characteristics and fasting serum endocrine parameters in first-, second- and third-born children. Age and MPHSDS data are mean ± SD; other data are means and 95% confidence intervals adjusted for other confounding factors (including birth parameters and age) in the multivariate models

	First-borns	Second-borns	Third-borns
n	157	119	36
Age (years)	8·1 ± 2·1	6·7 ± 1·8****†	5·8 ± 2·1****
Sex ratio (boys)	54%	54%	51%
Chronological age – bone age (years)	−0·19 ± 0·93	−0·15 ± 0·72	0·02 ± 0·53
Gestation (weeks)	39·8 (39·6–40·0)	39·6 (39·4–39·9)	39·4 (39·0–39·8)
Birth weight (kg)	3·48 (3·41–3·55)	3·59 (3·51–3·66)*	3·66 (3·52–3·81)*
HtSDS	1·08 (0·93–1·23)	0·67 (0·50–0·83)***	0·70 (0·39–1·00)*
MPHSDS	0·77 ± 0·72	0·90 ± 0·74	0·87 ± 0·91
HtSDS–MPHSDS	0·42 (0·29–0·55)	0·19 (0·06–0·32)***††	−0·14 (−0·37–0·08)****
BMISDS	−0·09 (−0·27–0·08)	−0·07 (−0·26–0·12)	0·04 (−0·32–0·40)
Abdominal adiposity	0·59 (0·56–0·62)	0·61 (0·58–0·64)†	0·71 (0·64–0·77)**
Body fat (%)	17·9 (16·8–18·9)	17·5 (16·3–18·6)	18·3 (16·1–20·5)
IGF-I (μg/l)	109 (101–118)	115 (106–124)††	96 (80–113)*
IGF-II (μg/l)	739 (723–755)	752 (735–769)	725 (693–757)
IGFBP-3 (μg/l)	2554 (2401–2707)	2647 (2487–2808)	2554 (2272–2836)

*$P < 0·05$; **$P < 0·01$; ***$P < 0·001$; ****$P < 0·0001$ for comparisons with first-borns; †$P < 0·05$; and ††$P < 0·01$ for comparison with third-borns. Abdominal adiposity is the android fat to gynoid fat ratio.

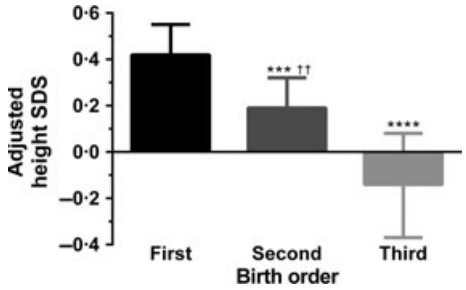

Fig. 2 Height SDS adjusted for mean parental height among first- (*n* = 157), second- (*n* = 119) and third-born (*n* = 36) children. Data are means and 95% confidence intervals, adjusted for other confounding factors in the multivariate model. ***$P < 0·001$, ****$P < 0·0001$ *vs* first-borns; ††$P < 0·01$ *vs* third-borns.

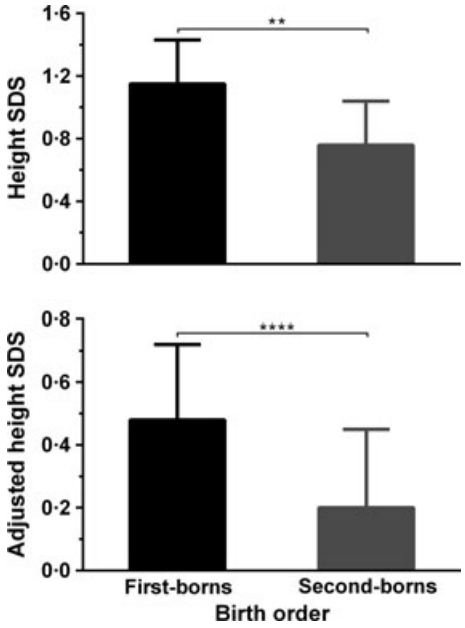

Fig. 3 Height SDS and height SDS adjusted for mean parental height from subgroup analyses on first- and second-born children from sibling pairs in the same family (*n* = 136). Data are means and 95% confidence intervals, adjusted for other confounding factors in the multivariate model. **$P < 0·01$ and ****$P < 0·0001$.

who were in turn taller than third-borns ($P = 0·007$; Table 2; Fig. 2). Further, when sibling pairs were assessed, both height SDS ($P = 0·009$) and adjusted height SDS ($P < 0·0001$) were lower in second-borns compared with first-born children (Fig. 3). Importantly, there were no differences in children's biological maturity (as assessed by bone age estimation) among groups (Tables 1 and 2).

Although total adiposity was unaffected by birth order, abdominal fat (android fat to gynoid fat ratio) was reduced in both first- ($P < 0·001$) and second-borns ($P = 0·004$) compared with the third-born children (Table 2). IGF-I concentrations were higher in both first- ($P = 0·043$) and second-borns ($P = 0·003$) compared with the third-borns (Table 2). Conversely, blood lipids and other hormonal parameters were unaffected by birth order (Tables 1 and 2).

There were no sex-dependent differences between boys and girls according to birth order. Exploratory analyses among first-borns on main study outcomes showed no differences between first-borns who had siblings (*n* = 109; 69%) compared with those who were an only child (*n* = 48; 31%).

Discussion

We found that first-born children were approximately 2·5 cm taller than later-borns, with birth order also having a graded

effect on height, with an incremental height reduction from first to third birth order. These differences equated to a mean height decrease of 1·3 cm from first- to second-borns, and a further decrease of 2·0 cm from second- to third-born children. Furthermore, in keeping with their taller stature, first- and second-borns had higher IGF-I concentrations than third-borns. This latter observation is consistent with our study findings, as IGF-I is an important mediator of childhood growth.[24]

The major strengths of our study were our contemporary cohort (born after the year 2000), consisting exclusively of children of higher socio-economic status (where nutrition was plentiful, irrespective of birth order) and of single ethnicity (New Zealand European). Importantly, each child's height was also individually adjusted for accurately measured parental heights (i.e. genetic potential). Furthermore, children across birth order groups had similar BMI, meaning that height differences were not driven by childhood obesity.[25] Notably, as there were no differences in biological maturity between groups (as assessed by bone age X-rays), our study indicates that the observed differences in height between birth order groups are more likely to persist into adulthood.[21]

Previous studies assessing the impact of birth order on childhood height also found that first-borns were 1–2 cm taller than later-born children.[3–5] However, their data were not corrected for parental heights, which are the most important predictors of offspring height.[21,26] In addition, these childhood studies included participants from all socio-economic groups, and only two studies included limited adjustments for socio-economic status.[3,5] The latter has a strong effect on height, with 1–2 cm differences observed between children of lower and higher socio-economic groups,[27] with more marked effects (2–6 cm) on adult height.[26] This issue is further compounded when we consider that greater family size (i.e. increasing birth order) is strongly associated with lower socio-economic status.[28] A large British study provided evidence that number of siblings also affects childhood height, independently of socio-economic status.[29] However, the latter study did not assess possible effects of birth order, and our data showed no differences in stature between first-borns who were an only child *vs* first-borns with siblings.

Adult studies demonstrating taller stature in first-borns have been conducted in developing countries,[6,8–10] where increasing family size reduces the availability of nutrition in childhood[30] and may explain the shorter stature of later-born offspring.[27] The only adult study conducted in a developed country comprised a cohort of adults born in post-war England, a time of limited availability of food.[7]

While children in all birth order groups in our study had similar BMI and total body fat percentage, third-born children had higher abdominal fat than first- and second-borns. Increased abdominal fat is a risk factor for the metabolic syndrome,[31] and third-born children may be at a greater risk of this disease than both first- and second-borns. The only other childhood study assessing the effect of birth order on childhood adiposity found that first-borns had a greater BMI than later-borns at 4 years of age, but similar BMI and body composition in adolescence.[6] Our findings also contrast with several adult studies that have found that first-borns had greater BMI and/or increased adiposity when compared with later-borns.[8,10] As our cohort consisted of prepubertal children, it remains possible that further differences in adiposity between first- and later-born children could emerge in adolescence or adulthood.

We found no effects of birth order on blood lipid profiles in childhood. Although this is the first study to examine such effects in children, one adult study found that first-borns had less favourable lipid profiles compared with later-borns.[10] As our cohort included prepubertal children, possible birth order effects on lipids may be yet to emerge.

There is no clear single explanation for the graded effect of birth order on childhood height. Possible explanations include increased levels of growth hormone (GH) and IGF-I receptors in first-borns compared with later-borns.[32] A study comparing first- and later-born sheep revealed marked differences in the hepatic GH–IGF axis.[32] Compared with later-borns, first-born lambs had a persistent increase in hepatic GH-receptor mRNA,[32] as well as up-regulated hepatic IGF-I receptor mRNA.[32] These receptor differences were accompanied by a trend towards a higher crown to rump length in first-born 1-month-old lambs.[32] These findings suggest that first-borns may have increased GH and IGF-I receptor responsiveness, and increased growth may accompany these receptor differences.

Implantation and placentation also seem to differ between first and later pregnancies, and first-born foetuses may receive a reduced nutrient supply *in utero* compared with their later-born siblings.[33] However, "foetal restriction" is associated with shorter stature in childhood,[34] and this mechanism is inconsistent with our findings of taller stature among first-born children. Alternatively, differences in implantation and placentation between first- and later-borns may trigger subtle epigenetic changes in imprinted genes regulating childhood growth. Birth order has been previously described to alter imprinted genes involved in growth, such as H19 and IGF-II.[35] Therefore, it is possible that birth order may lead to alterations in placental imprinted genes, leading to subsequent changes in childhood growth.

Possible limitations of this study include the age differences between birth order groups, but children's heights and BMI were converted to SDS to minimize possible effects of age and gender on auxological outcomes. Furthermore, not only were other measured outcomes corrected for age in statistical models (where appropriate), there were also no differences in biological maturity among groups. There was also a relatively small number of third-born children ($n = 36$), but this group was still large enough for important differences between birth order groups to be detected. In addition, as our cohort comprised a homogenous group of children of same ethnicity and higher socio-economic status, our findings may not be directly applicable to the general population. However, this homogeneity means that we eliminated these two important factors known to affect phenotype and metabolism in childhood, so that the effects of birth order could better be evaluated.

In conclusion, we observed that first-born children were taller than later-borns, with an incremental height reduction observed from first to third birth order. Overall, the mechanisms respon-

sible for these differences remain unexplained and further investigation is required. Given the continuing worldwide trend towards smaller families, the proportion of first-borns in the population is likely to continue to grow. As a result, the possible effects of birth order on childhood and adult phenotype and disease risk warrant further evaluation.

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Author contributions

All authors conceived and designed the study. TS performed the clinical study. TS, HLM, FM and JGBD compiled the data, which were analysed by JGBD. TS wrote the initial drafts of the manuscript which were revised by JGBD and WSC, with input from HLM, FM and PLH. TS and WSC are the guarantors.

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References

1 Eurostat (2011) Key figures on Europe. Eurostat pocketbook. Publications Office of the European Union, Luxembourg.
2 Sobotka, T. & Toulemon, L. (2008) Overview Chapter 4: changing family and partnership behaviour: common trends and persistent diversity across Europe. *Demographic Research*, **19**, 85–138.
3 Whitley, E., Gunnell, D., Davey Smith, G. *et al.* (2008) Childhood circumstances and anthropometry: the Boyd Orr cohort. *Annals of Human Biology*, **35**, 518–534.
4 Tanner, J. (1989) Foetus Into Man—Physical Growth from Conception to Maturity. Castlemead, Ware, UK.
5 Wingerd, J. & Schoen, E.J. (1974) Factors influencing length at birth and height at five years. *Pediatrics*, **53**, 737–741.
6 Wells, J.C.K., Hallal, P.C., Reichert, F.F. *et al.* (2011) Associations of birth order with early growth and adolescent height, body composition, and blood pressure: prospective birth cohort from Brazil. *American Journal of Epidemiology*, **174**, 1028–1035.
7 Kuh, D. & Wadsworth, M. (1989) Parental height: childhood environment and subsequent adult height in a national birth cohort. *International Journal of Epidemiology*, **18**, 663–668.
8 Dahly, D.L. & Adair, L.S. (2010) Does lower birth order amplify the association between high socioeconomic status and central adiposity in young adult Filipino males. *International Journal of Obesity*, **34**, 751–759.
9 Ghosh, J.R. & Bandyopadhyay, A.R. (2006) Income, birth order, siblings, and anthropometry. *Human Biology*, **78**, 733–741.
10 Siervo, M., Horta, B.L., Stephan, B.C.M. *et al.* (2010) First-borns carry a higher metabolic risk in early adulthood: evidence from a prospective cohort study. *PLoS ONE*, **5**, e13907.
11 Ayyavoo, A., Savage, T., Derraik, J.G.B. *et al.* (2013) First-born children have reduced insulin sensitivity and higher daytime blood pressure compared to later-born children. *Journal of Clinical Endocrinology and Metabolism*.
12 Lawlor, D.A., Najman, J.M., Sterne, J. *et al.* (2004) Associations of parental, birth, and early life characteristics with systolic blood pressure at 5 years of age. *Circulation*, **110**, 2417–2423.
13 Cardwell, C.R., Stene, L.C., Joner, G. *et al.* (2011) Birth order and childhood type 1 diabetes risk: a pooled analysis of 31 observational studies. *International Journal of Epidemiology*, **40**, 363–374.
14 Savage, T., Peek, J.C., Robinson, E.M. *et al.* (2012) Ovarian stimulation leads to shorter stature in childhood. *Human Reproduction*, **27**, 3092–3099.
15 Gerritsen, S., Stefanogiannis, N. & Galloway, Y. (2008) A Portrait of Health: Key Results of the 2006/07 New Zealand Health Survey. Ministry of Health, Wellington.
16 Schilg, S. & Hulse, T. (1997) Growth Monitoring and Assessment in the Community: A Guide to Good Practice. Child Growth Foundation, London.
17 Novotny, R., Going, S., Teegarden, D. *et al.* (2007) Hispanic and Asian pubertal girls have higher android/gynoid fat ratio than whites. *Obesity*, **15**, 1565–1570.
18 Shear, C.L., Freedman, D.S., Burke, G.L. *et al.* (1987) Body fat patterning and blood pressure in children and young adults. The Bogalusa Heart Study. *Hypertension*, **9**, 236–244.
19 Greulich, W.W. & Pyle, S.I. (1959) Radiographic Atlas of Skeletal Development of the Hand and Wrist. Stanford Univ Pr, Stanford.
20 De Onis, M. & Habicht, J.P. (1996) Anthropometric reference data for international use: recommendations from a World Health Organization Expert Committee. *American Journal of Clinical Nutrition*, **64**, 650–658.
21 Tanner, J., Whitehouse, R., Marshall, W. *et al.* (1975) Prediction of adult height from height, bone age, and occurrence of menarche, at ages 4 to 16 with allowance for midparent height. *Archives of Disease in Childhood*, **50**, 14–26.
22 Freeman, J.V., Cole, T.J., Chinn, S. *et al.* (1995) Cross sectional stature and weight reference curves for the UK, 1990. *Archives of Disease in Childhood*, **73**, 17–24.
23 Matthews, D., Hosker, J., Rudenski, A. *et al.* (1985) Homeostasis model assessment: insulin resistance and β-cell function from fasting plasma glucose and insulin concentrations in man. *Diabetologia*, **28**, 412–419.
24 Laron, Z. (2001) Insulin-like growth factor 1 (IGF-1): a growth hormone. *Molecular Pathology*, **54**, 311–316.

25 Cameron, N., Pettifor, J., De Wet, T. *et al.* (2003) The relationship of rapid weight gain in infancy to obesity and skeletal maturity in childhood. *Obesity*, **11**, 457–460.
26 Silventoinen, K. (2003) Determinants of variation in adult body height. *Journal of Biosocial Science*, **35**, 263–285.
27 Jansen, W. & Hazebroek-Kampschreur, A. (1997) Differences in height and weight between children living in neighbourhoods of different socioeconomic status. *Acta Paediatrica*, **86**, 224–225.
28 Newman, L.A. (2009) Do socioeconomic differences in family size reflect cultural differences in confidence and social support for parenting? *Population Research and Policy Review*, **28**, 661–691.
29 Lawson, D.W. & Mace, R. (2008) Sibling configuration and childhood growth in contemporary British families. *International Journal of Epidemiology*, **37**, 1408–1421.
30 Smith, L.C. & Haddad, L.J. (2000) Explaining Child Malnutrition in Developing Countries: A Cross-Country Analysis. Intl Food Policy Research Inst, Washington, DC.
31 Després, J.P. & Lemieux, I. (2006) Abdominal obesity and metabolic syndrome. *Nature*, **444**, 881–887.
32 Hyatt, M.A., Budge, H., Walker, D. *et al.* (2007) Effects of maternal parity and late gestational nutrition on mRNA abundance for growth factors in the liver of postnatal sheep. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology*, **292**, R1934–R1942.
33 Prefumo, F., Ganapathy, R., Thilaganathan, B. *et al.* (2006) Influence of parity on first trimester endovascular trophoblast invasion. *Fertility and Sterility*, **85**, 1032–1036.
34 Chernausek, S.D. (2012) Update: consequences of abnormal fetal growth. *Journal of Clinical Endocrinology and Metabolism*, **97**, 689–695.
35 Petry, C., Ong, K., Barratt, B. *et al.* (2005) Common polymorphism in H19 associated with birthweight and cord blood IGF-II levels in humans. *BMC Genetics*, **6**, 22.