Eur J Pediatr (2014) 173:623–627
DOI 10.1007/s00431-013-2226-x

ORIGINAL ARTICLE

Neonatal anthropometrics and body composition in obese children investigated by dual energy X-ray absorptiometry

Ulrik Lausten-Thomsen · Tenna Ruest Haarmark Nielsen · Ida Näslund Thagaard · Torben Larsen · Jens-Christian Holm

Received: 23 August 2013 / Accepted: 21 November 2013 / Published online: 7 December 2013

Abstract Epidemiological and animal studies have suggested an effect of the intrauterine milieu upon the development of childhood obesity. This study investigates the relationship between body composition measured by dual energy X-ray absorptiometry expressed as body fat percent, body fat mass index (BFMI), and fat free mass index (FFMI) in obese children and the preceding in utero conditions expressed by birth weight, birth length, and birth weight for gestational age. The study cohort consisted of 776 obese Danish children (median age 11.6 years, range 3.6–17.9) with a mean Body Mass Index Standard Deviation Score (BMI SDS) of 2.86 (range 1.64–5.48) treated in our national referral centre. In a linear general regression model adjusted for age, gender, socioeconomic status, and duration of breastfeeding, we found the body fat percent, FFMI, and BFMI at the time of enrolment in childhood obesity treatment to be significantly correlated with both birth weight and birth weight for gestational age. *Conclusion*: These results indicate a prenatal influence upon childhood obesity. Although there are currently no sufficient data to suggest any recommendations to pregnant women, it is possible that the prenatal period may be considered as a potential window of opportunity for prevention of childhood overweight and obesity.

Keywords Birth weight · Childhood obesity · DXA · DOHaD (Developmental Origins of Health and Disease)

U. Lausten-Thomsen (✉) · T. R. H. Nielsen · J.-C. Holm
The Children's Obesity Clinic, Department of Paediatrics, Copenhagen University Hospital Holbaek, Smedelundsgade 60, 4300 Holbaek, Denmark
e-mail: ult@dadlnet.dk

I. N. Thagaard · T. Larsen
Department of Gynaecology and Obstetrics, Copenhagen University Hospital Holbaek, Holbaek, Denmark

J.-C. Holm
Institute of Clinical Medicine, Faculty of Health and Medical Sciences, University of Copenhagen, Copenhagen, Denmark

Introduction

Childhood obesity is globally increasing across gender and ethnic groups and has been recognized as an important public health problem due to the associated complications [12]. Obesity is defined as an excess of body fat accumulation [13] and various methods of estimation hereof exist. The body mass index (BMI), calculated as weight divided by height squared, has been widely used in paediatrics owing to the relative ease with which measurements can be made. Although debatable, an often-used definition is a BMI above the 95th percentile for age and gender [2].

However, BMI is a crude surrogate measure of body composition especially in children during growth and development [36] and a far more accurate method is dual energy X-ray absorptiometry (DXA scans). With cost as the only major disadvantage, it has replaced hydrodensiometry as the gold standard for body composition assessment [11, 30], as it allows for accurate measurements of body constituents. However, the utility hereof is to a certain degree hampered by the lack of well-defined and accepted reference values for children [28]. Studies have demonstrated that there is a large discrepancy between BMI- and DXA-defined adiposity status, which is both gender and age specific [18].

The aetiology of childhood obesity is complex and multifactorial and has among others been linked to genetic [3], metabolic [21], nutritional [21], activity [22], socioeconomic [33], psychological [4, 5], as well as prenatal factors. The prenatal life is a time of rapid growth, cellular replication and differentiation, and functional maturation of organ systems. These processes are very sensitive to disturbances of the intrauterine milieu [29]. It is becoming increasingly apparent that the in utero environment in which a foetus develops may have long-term effects on subsequent health and survival [6, 7, 29, 30]. Accordingly, increasing circumstantial evidence for the prenatal initiation of childhood obesity has emerged [16, 19, 30]. Birth weight is frequently used as an indicator of in utero conditions [9], and a number of epidemiological studies have demonstrated relationship between birth weight (BW) and subsequent BMI in childhood and/or adult life [20, 24, 26, 31, 37]. However, birth weight depends largely on the duration of the pregnancy and should consequently be related to gestational age (GA) to estimate the relative birth weight.

As very few studies have investigated the relationship between birth weight and subsequent body composition in obese children and adolescents, the present study aims to further explore the relationship between body composition expressed as fat free mass index (FFMI), body fat mass index (BFMI), and BF% in a cohort of severely obese Danish children and adolescents and their preceding in utero conditions expressed by birth weight and birth weight for gestational age (BWfGA).

Material and methods

Subjects The study population was obese children treated between October 2009 and March 2013 at the Children's Obesity Clinic, Copenhagen University Hospital Holbaek, Denmark using The Children's Obesity Clinics Treatment Protocol [15]. Inclusion criteria were childhood obesity defined as a BMI above the 95th percentile for gender and age [25] at the time of the DXA scan and age between 3 and 18 years. All participants and/or parents signed informed consent. The study was approved by the Danish Data Protection Agency and the Regional Scientific Ethics Committee (SJ-104) and is registered at Clinical Trials (NCT00928473).

Anthropometric measurements All study participants were examined by skilled research assistants immediately before the DXA examination. Height and weight while wearing light indoor clothes and no shoes were measured using, respectively, a stadiometer to the nearest millimetre and a Soehnle Digital weight indicator (Professional 2755, Soehnle, Backnang, Germany) to the nearest 100 g. BMI Standard Deviation Score (SDS) was calculated according to the Danish BMI charts [25]. The degree of baseline obesity is expressed in SDS in order to adjust for age-related variation in reference intervals. The 95th percentile is equivalent to +1.64 SDS and the 99th percentile to +2.33 SDS defining the following groups: obesity (SDS 1.64 to 2.32) and severe obesity (SDS ≥2.33). Additional data on gender, age, socioeconomic status, birth weight, birth length, GA, gestational diabetes, and duration of breastfeeding were obtained through a structured family interview and hospital records. BWfGA was estimated by calculating the expected birth weight for term using previously published data from a Scandinavian birth cohort [23]. Birth weight for gestational age was defined as small for GA (SGA) (below −2SDS), appropriate for GA (AGA), or heavy for GA (HGA) (above +2SD) [1].

DXA scans All study participants were investigated by DXA performed according to the procedures recommended by the manufacturer on a GE Lunar iDXA scanner (ME + 200179, GE Healthcare, Little Chalfont, UK) yielding data on body fat percent (BF%), body fat mass (BFM), and fat free mass (FFM). Since both BFM and FFM must be normalized to height in order to take growth and development into consideration and thus make useful comparisons [17, 35, 36], the BFMI and the FFMI were calculated as mass (kg)/height $(m)^2$. As studies have demonstrated that healthy girls experience a graduate increase in BF through childhood and adolescence whereas healthy boys have a more stable BF % during the same period of time [34], the data was analyzed separately for each gender subsequently adjusted for age.

Statistical analyses Data was analyzed by generalized linear model for correlation between neonatal anthropometrics (i.e. BW, BL, and BWfGA) and body composition in subsequent obesity (i.e. fat percent, BFMI, and FFMI). Data was adjusted for age, height, socioeconomic status, and duration of breastfeeding. Differences between groups were analyzed using Kruskal–Wallis test. Data was logarithmically transformed when appropriate. Statistical modelling was performed using the R software version 2.15.3.

Results

The study included 776 children found to be obese (n = 168) or severely obese (n =608). There were more girls than boys (433 vs. 343, p <0.001). As expected, the boys were significantly larger at birth when comparing absolute birth weight and length, but no such difference was found when data was adjusted for gender and gestational age. Additional detailed baseline descriptive statistics are given in Table 1.

In a generalized linear model adjusted for age, height, socioeconomic status, and duration of breastfeeding, a significant correlation between the birth weight and subsequent degree of childhood obesity expressed as body fat percent, BFMI, and FFMI was found in both boys and girls (see Table 2).

When taking into account the relative birth weight, the BWfGA was equally found to be significantly correlated to fat percent, BFMI and FFMI in a generalized linear model (see

Table 1 Descriptive characteristics at birth and at DXA scan

	All patients (n=776)	Boys (n=343)	Girls (n=433)	p value
Infancy				
GA (days)	283 [207;308]	283 [207;308]	283 [210;308]	0.671
BW (g)	3575 [947;5,210]	3650 [1,440;5,270]	3,540 [947;5,200]	0.032
BL (cm)	52 [36;59]	53 [39;59]	52 [36;58]	<0.001
BWfGA SDS	−0.03 [−6.30; 3.06]	−0.07 [−6.21; 2.33]	0.01 [−6.30; 3.06]	0.418
PI (kg/m^3)	2.52 [1.29; 4.19]	2.49 [1.29; 3.70]	2.54 [1.46; 4.19]	0.031
Breastfeeding (months)	4 [0;60]	4 [0;30]	4[0;60]	0.989
At the DXA scan				
Age (years)	11.60 [3.64; 17.93]	11.72 [4.53; 17.93]	11.54 [3.64; 17.87]	0.849
BMI SDS	2.86 [1.64; 5.48]	3.06 [1.64; 5.48]	2.74 [1.66; 5.17]	<0.001
Social class	3 [1;5]	3 [1;5]	3 [1;5]	0.944
Fat percentage	43.4 [26.7;62.1]	41.9 [26.7; 54.7]	43.9 [33.0; 62.1]	<0.001
FFMI [kg/ht(m^2)]	14.69 [10.14; 24.38]	14.62 [10.14; 24.38]	14.78 [10.53; 22.58]	0.286
BFMI [kg/ht(m^2)]	11.25 [5.12; 33.75]	10.93 [5.12; 26.80]	11.49 [6.45; 33.75]	0.002

Values are medians and range. p values are Wilcoxon–Mann–Whitney test between genders

GA gestational age, *BW* birth weight, *BL* birth length, *BWfGA SDS* birth weight for gestational age and gender, *SDS* standard derivation score, *PI* ponderal index, *DXA* dual energy X-ray absorptiometry, *BMI* body mass index, *FFMI* fat free mass index, *BFMI* body fat mass index

Table 2). Pre- or post-term birth did not correlate to body composition in childhood obesity as no association between duration of pregnancy and body fat percentage, BFMI, or FFMI was found (data not shown). Furthermore, the excluding of any known cases of gestational diabetes did not alter the results (data not shown). Finally, no difference was found when comparing preterm, term, and post-term children (Kruskal–Wallis; boys/girls p values were, respectively, p, 0.24/0.14; p, 0.43/0.22; p, 0.32/0.89).

In order to explore the full spectrum in regards to BWfGA, the SGA, AGA, and HGA groups were compared, but no additional association in body fat percentage, BFMI, or FFMI were demonstrated for either gender (Kruskal–Wallis; respective p values for boys/girls: p, 0.22/0.78; p, 0.32/0.92; p, 0.35/0.89).

Table 2 Correlation between neonatal anthropometrics and body composition

	Boys (n=343)	Girls (n=433)
BFMI/BW	<0.001	<0.001
FFMI/BW	<0.001	<0.001
Fat percent/BW	<0.001	<0.001
BFMI/BWfGA	0.038	0.016
FFMI/BWfGA	0.034	0.008
Fat percent/BWfGA	0.020	0.019
BFMI/BL	0.104	0.054
FFMI/BL	0.064	0.004
Fat percent/BL	0.131	0.107

Values are p values from generalized linear models adjusted for age, height, socioeconomic status, and duration of breastfeeding

BFMI body fat mass index, *BW* birth weight, *FFMI* fat free mass index, *BWfGA* birth weight for gestational age, and gender, *BL* birth length

Discussion

In this cohort of severely obese children, the birth weight was found to be significantly correlated to the subsequent degree of body fat percent, BFMI, and FFMI in both girls and boys later in childhood. Similarly, significant correlations between the relative birth weight (i.e. BWfGA) and body fat, BFMI, and FFMI in both girls and boys were demonstrated. Our findings demonstrate that neonatal anthropometrics, exemplified by birth weight and birth weight for gestational age, relate to subsequent childhood obesity and thereby adds to the growing evidence of the association between childhood obesity and the intrauterine nutritional environment.

Importantly, our data support a linear association with no apparent increase among the low BWfGA. This is in consistence with recent metanalyses on the subject [37] and our previous findings of the association between neonatal anthropometrics and BMI SDS in a similar but larger cohort [20]. It is noteworthy that birth weight and not birth length was associated with subsequent obese body composition. This may reflect that the birth weight and relative birth weight much more accurately reflect nutritional status in utero and thereby are better predictors of subsequent obesity risk [10].

The strength of this retrospective observational cohort study is both the number of included children and more importantly the use of DXA scans for assessment of body composition as this greatly enhances the accuracy of the clinical data. Furthermore, the major shortcoming of BMI is that it only measures excess weight; consequently, the use of DXA-derived body composition in this study offers superior specificity because the data is based on fat mass not body weight [17]. Finally, many interview or questionnaire-based studies on overweight subjects are prone to bias as overweight individuals tend to underestimate their weight relative to their height [32]. As all measurement in this study were done in-house, the presented data can be considered valid regarding the two major potential biases in this subject: the degree of childhood obesity (i.e. the DXA scan derived data as well as height and weight) and birth weight and length. The socio-economic status of the families as well as the duration of breast feeding were self-reported and therefore subject to well-known potential bias. Still, it is less likely for any systematized bias to have influenced the data.

Recent evidence suggests that functional maturation of organ systems and tissues in the developing foetus is very sensitive to alterations of the nutritional milieu and as an example substrate excess has profound effect on the foetal, placental, maternal, hormonal, and metabolic interactions [29, 30].

In both normal and compromised pregnancies, nutrients drive intrauterine growth by providing substrate for tissue accretion whereas hormones regulate the nutrient distribution [27]. The interactions leading to high birth weight are complex. Although classically exemplified by maternal hyperglycaemia leading to foetal hyperinsulinism, they also include for example the stimulatory effect of free amino acids on the development of the foetal β cells as well as the effect of maternal levels of triglycerides and free fatty acids [14, 27]. Despite that weight and body composition is highly heritable, known genes account for only a modest proportion of their variance [8]. Logically, the genes cannot alone explain the rapid increase in obesity prevalence as the genetic characteristics of the human population have not changed during the rapid increase in obesity prevalence over the last few decades [8].

Yet, whether the birth weight associated increase in risk childhood obesity that was observed in this study simply represents an epiphenomenon is currently undetermined. It is however possible that the prenatal period may be considered as a potential window of opportunity for prevention of childhood obesity and that anthropological measurements in theory could be used to help identify neonates at high risk for developing childhood obesity. However, there are currently not sufficient data to suggest any recommendations to pregnant women. Consequently, further research on the aetiopathogenic mechanisms underlying this association is warranted as increased knowledge hereof may theoretically lead to the development of future primary prenatal prevention strategies for childhood obesity and obesity-related diseases.

Acknowledgments This study is part of the research activities in TARGET (The impact of our genomes on individual treatment response in obese children, see www.TARGET.ku.dk), BIOCHILD (Genetic and systems biology of childhood obesity in India and Denmark, see www.biochild.ku.dk), and The Obesity Research Centre (DanORC, see ww.danorc.dk). TARGET, BIOCHILD, and DanORC are all supported by the Danish Council for Statetic Research (grants 11-115917, 11-116714, and 2101-06-0005). In addition, this study is part of the Danish Childhood Obesity Biobank (ClinicalTrails.gov ID-no: NCT00928473) and is financially supported by The Region Zealand Health Sciences Research Foundation.

Conflict of interest The authors declare that they have no personal financial relationship with the sponsoring organizations or other potential conflicts of interest.

References

1. Balchin I, Peebles D (2012) Fetal growth, intrauterine growth restriction and small-for-gestational-age babies. In: Rennie J (ed) Rennie & Roberton's Textbook of Neonatology, 5th edn. Churchill Livingstone, London, pp 175–188
2. Barlow SE (2007) Expert committee recommendations regarding the prevention, assessment, and treatment of child and adolescent overweight and obesity: summary report. Pediatrics 120(Suppl 4):S164–S192
3. Bennett WI (1995) Beyond overeating. N Engl J Med 332(10):673–674
4. Carey WB (1985) Temperament and increased weight gain in infants. J Dev Behav Pediatr 6(3):128–131
5. Christoffel KK, Forsyth BW (1989) Mirror image of environmental deprivation: severe childhood obesity of psychosocial origin. Child Abuse Negl 13(2):249–256
6. Curhan GC, Chertow GM, Willett WC, Spiegelman D, Colditz GA, Manson JE, Speizer FE, Stampfer MJ (1996) Birth weight and adult hypertension and obesity in women. Circulation 94(6):1310–1315
7. Curhan GC, Willett WC, Rimm EB, Spiegelman D, Ascherio AL, Stampfer MJ (1996) Birth weight and adult hypertension, diabetes mellitus, and obesity in US men. Circulation 94(12):3246–3250
8. Entringer S, Buss C, Swanson JM, Cooper DM, Wing DA, Waffern F, Wadhwa PD (2012) Fetal programming of body composition, obesity, and metabolic function: the role of intrauterine stress and stress biology. J Nutr Metab 2012:632548
9. Fallucca S, Vasta M, Sciullo E, Balducci S, Fallucca F (2009) Birth weight: genetic and intrauterine environment in normal pregnancy. Diabetes Care 32(12):e149
10. Field AE, Laird N, Steinberg E, Fallon E, Semega-Janneh M, Yanovski JA (2003) Which metric of relative weight best captures body fatness in children? Obes Res 11(11):1345–1352
11. Frisard MI, Greenway FL, DeLany JP (2005) Comparison of methods to assess body composition changes during a period of weight loss. Obes Res 13(5):845–854
12. Han JC, Lawlor DA, Kimm SY (2010) Childhood obesity. Lancet 375(9727):1737–1748
13. Haslem DW (2005) Obesity. Lancet 366(9492):1197–209
14. Hawdon JM (2012) Fetal growth, intrauterine growth restriction and small-for-gestational-age babies. In: Rennie J (ed) Rennie & Roberton's Textbook of Neonatology, 5th edn. Churchill Livingstone, London, pp 388–394
15. Holm JC, Gamborg M, Bille DS, Gr Nb KH, Ward LC, Faerk J (2011) Chronic care treatment of obese children and adolescents. Int J Pediatr Obes 6(3–4):188–196
16. Huang JS, Lee TA, Lu MC (2007) Prenatal programming of childhood overweight and obesity. Matern Child Health J 11(5):461–473
17. Kelly TL, Wilson KE, Heymsfield SB (2009) Dual energy X-Ray absorptiometry body composition reference values from NHANES. PLoS One 4(9):e7038
18. Kennedy AP, Shea JL, Sun G (2009) Comparison of the classification of obesity by BMI vs. dual-energy X-ray absorptiometry in the Newfoundland population. Obesity (Silver Spring) 17(11):2094–2099

19. Lamb MM, Dabelea D, Yin X, Ogden LG, Klingensmith GJ, Rewers M, Norris JM (2010) Early-life predictors of higher body mass index in healthy children. Ann Nutr Metab 56(1):16–22
20. Lausten-Thomsen U, Bille DS, Nasslund I, Folskov L, Larsen T, Holm JC (2013) Neonatal anthropometrics and correlation to childhood obesity—data from the Danish children's obesity clinic. Eur J Pediatr 172(6):747–751
21. Leibel RL, Rosenbaum M, Hirsch J (1995) Changes in energy expenditure resulting from altered body weight. N Engl J Med 332(10):621–628
22. Li R, O'Connor L, Buckley D, Specker B (1995) Relation of activity levels to body fat in infants 6 to 12 months of age. J Pediatr 126(3): 353–357
23. Marsal K, Persson PH, Larsen T, Lilja H, Selbing A, Sultan B (1996) Intrauterine growth curves based on ultrasonically estimated foetal weights. Acta Paediatr 85(7):843–848
24. Monasta L, Batty GD, Cattaneo A, Lutje V, Ronfani L, van Lenthe FJ, Brug J (2010) Early-life determinants of overweight and obesity: a review of systematic reviews. Obes Rev 11(10):695–708
25. Nysom K, Molgaard C, Hutchings B, Michaelsen KF (2001) Body mass index of 0 to 45-y-old Danes: reference values and comparison with published European reference values. Int J Obes Relat Metab Disord 25(2):177–184
26. Rugholm S, Baker JL, Olsen LW, Schack-Nielsen L, Bua J, Sorensen TI (2005) Stability of the association between birth weight and childhood overweight during the development of the obesity epidemic. Obes Res 13(12):2187–2194
27. Sferruzzi-Perri AN, Vaughan OR, Forhead AJ, Fowden AL (2013) Hormonal and nutritional drivers of intrauterine growth. Curr Opin Clin Metab Care 16(3):298–309
28. Shypailo RJ, Butte NF, Ellis KJ (2008) DXA: can it be used as a criterion reference for body fat measurements in children? Obesity (Silver Spring) 16(2):457–462
29. Simmons RA (2009) Developmental origins of adult disease. Pediatr Clin North Am 56(3):449–66
30. Simmons R (2008) Perinatal programming of obesity. Semin Perinatol 32(5):371–374
31. Sorensen HT, Sabroe S, Rothman KJ, Gillman M, Fischer P, Sorensen TI (1997) Relation between weight and length at birth and body mass index in young adulthood: cohort study. BMJ 315(7116):1137
32. Stewart AW, Jackson RT, Ford MA, Beaglehole R (1987) Underestimation of relative weight by use of self-reported height and weight. Am J Epidemiol 125(1):122–126
33. Stunkard AJ, Sorensen TI (1993) Obesity and socioeconomic status—a complex relation. N Engl J Med 329(14):1036–1037
34. van der Sluis IM, de Ridder MA, Boot AM, Krenning EP, de Muinck Keizer-Schrama SM (2002) Reference data for bone density and body composition measured with dual energy x ray absorptiometry in white children and young adults. Arch Dis Child 87(4):341–347
35. VanItallie TB, Yang MU, Heymsfield SB, Funk RC, Boileau RA (1990) Height-normalized indices of the body's fat-free mass and fat mass: potentially useful indicators of nutritional status. Am J Clin Nutr 52(6):953–959
36. Wells JC (2001) A critique of the expression of paediatric body composition data. Arch Dis Child 85(1):67–72
37. Yu ZB, Han SP, Zhu GZ, Zhu C, Wang XJ, Cao XG, Guo XR (2011) Birth weight and subsequent risk of obesity: a systematic review and meta-analysis. Obes Rev 12(7):525–542