Overweight and obesity in children: a study of weight-related anthropometric variables in childhood

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Measure what is measureable,
and make measureable what is not so…
Galileo Galilei
(1564–1643)

Table of contents

1.0 Preface

1.1 Acknowledgements

Data in this study are entirely based upon the Bergen Growth Study (www.vekststudien.no), conducted in 2003–2006. Initial planning, study execution, and data assembly were led by principal investigator Dr. Pétur B. Júlíusson and Professor Robert Bjerknes. Both have acted as supervisors in this study; Dr. Júliússon has been the principal supervisor.

My work started when I was responsible for the paediatric outpatient clinic at Stavanger University Hospital. We experienced an increasing amount of referrals of overweight children, and there was a need for an assessment and action plan for these children. I therefore contacted Dr. Júlíusson at Haukeland University Hospital, as I knew he was working in this field in Bergen. During our contact Dr. Júlíusson invited me to participate in a study where the main outcome was to establish a new national reference for waist circumference in Norwegian children. The collaboration with Dr. Júlíusson and Professor Bjerknes was exclusively positive, giving me new perspectives and leading me into the very interesting fields of anthropometry and overweight, as well as into scientific work. I am very grateful to Dr. Júlíusson and Professor Bjerknes for inviting me into the Bergen Growth Study, for their generosity with sharing their data, competence, and knowledge with me, for friendship, and for invaluable support in all aspects during this work.

This research has been performed in close collaboration with biostatistician Mathieu Roelants in the Laboratorium Anthropogenetica at the Free University of Brussels and the University of Leuven, Belgium. Dr. Roelants has also acted as co-supervisor. He has been very important in the construction of references, guiding me through the LMS method, and he has given very constructive advice in the process of writing scientific papers. He has undoubtedly lifted the quality of my work, and I very much appreciate his efforts.

I am also very thankful for the support and kindness of professor and biostatistician Geir Egil Eide at the University of Bergen. Professor Eide has patiently guided me through the jungle of statistical methods, he has taken

part in our discussions, and he has been part of the Bergen Growth Study from the very beginning.

The University of Bergen gave me a PhD scholarship that made it possible for me to work full-time on this project, for which I am very grateful.

I would like to thank the Paediatric Department and the Department of Research at Stavanger University Hospital for financial support and other facilities during my scholarship. I specifically mention professor and colleague Knut Øymar at the Paediatric Department, who has through years built up a scientific environment and awareness for scientific thinking in our department. Furthermore, I am grateful to our current director at the Division of Obstetrics Gynaecology and Paediatrics, Henning Garsjø; our former director, Sissel Moe Lichtenberg; current chief at the Paediatric Department, Kari Gjeraldstveit; and professor Stein Tore Nilsen, director at the Department of Research at Stavanger University Hospital, for their positive attitude to this project, and for financial support. I also want to thank my immediate chief and colleague at the Paediatric Department, Ann Marit Gilje, for support, flexibility, and friendship during this time. Thanks to all my friends and colleagues for their support and encouragement.

Last but not least, thanks to my family: my parents for their continuous encouragement and believing in me. Thanks to our children, Ludvig (17) and Sunniva (12), for their love and inspiration, and to my husband, Christian, for his lovingly support in all aspects of my life, for his enthusiasm for this project, and his endless support in ‘typographic and technical’ issues, especially when my computer doesn’t speak my language.
Thank you!

Stavanger, 2015
Bente Brannsether-Ellingsen

1.2 Summary of thesis

Background

Prevention of childhood overweight relies largely on public systems with repeated measurements of the child population from a very early age. So far, anthropometric measurements are the preferred tool in screening or large field studies. Body mass index (BMI) with standardized cut-off values is frequently used to diagnose overweight and obesity, but has significant limitations in childhood, and gives no information about fat distribution. Other weight-related anthropometric measurements, such as waist circumference, waist-to-height ratio, and the thickness of subcutaneous skinfolds, give additional information about fat distribution and possible health risks in children. The detection of unexpectedly large BMI changes may be important for early detection and prevention of overweight development.

Aims

The aims of this work were to study the weight-related anthropometric variables; waist circumference (WC), waist-to-height ratio (WHtR), triceps (TSF) and subscapular (SSF) skinfolds, by developing growth models and calculate the distributions of these variables in a representative sample of healthy Norwegian children. Further to study possible cut-offs for these variables in relation to the International Obesity Task Force (IOTF) BMI definition of overweight and obesity, and to look upon the interrelationships between BMI and these variables during childhood. Finally we wanted to evaluate conditional change in standardized BMI (BMI SDS) as an alternative method to evaluate BMI changes.

Methods

Four samples of children from the cross-sectional Bergen Growth Study (BGS) were used. Growth models were developed and the distributions of WC, WHtR, SSF, and TSF were calculated by the LMS method. Cut-offs in relation to overweight and obesity as defined by the IOTF´s BMI criteria, were studied by means of Receiver Operating Characteristics (ROC) analysis.

The interrelationships between weight-related anthropometric variables were studied by correlation and linear regression analyses. Sitting height (SH)

and waist-to-sitting-height ratio (WSHtR) were included in these analysis in addition to previous mentioned variables.

Annual BMI increments were studied, and the impact of sex, age, height, weight, BMI, and weight status on BMI and standardized BMI (BMI SDS) increments were assessed by linear regression analyses. Based on annual correlations between BMI SDS measurements, conditional changes in BMI SDS were calculated. The method was evaluated by comparing actual and predicted change.

Results

The distributions of WC, WHtR, SSF, and TSF were presented as percentiles. Mean WC increased with age, with significantly higher values for boys at almost all ages. Mean WHtR decreased with age until early adolescence and thereafter increased slightly towards adult age. For WHtR differences between the sexes were neither consistent nor statistically significant. The WC of Norwegian children was in the lower range compared with other European countries.

In general the mean values for skinfolds increased with age. Skinfolds were significantly larger for girls than for boys at all ages.

In relation to the IOTF's BMI definition of overweight and obesity, cut-offs could be defined for WC, suitable for use between 4–18 years of age, but not for WHtR, where optimal cut-off differed largely by age. The cut-offs for WC that minimized the false positive rate with acceptable sensitivity, were 1.0 SDS (close to the 85th percentile) to detect overweight, and 1.6 SDS (close to the 95th percentile) to detect obesity. It was also possible to define cut-offs for both skinfolds suitable for use between 4–16 years of age in relation to overweight and obesity. The cut-offs that minimized the false positive rate were 1 SDS (close to the 85th percentile) for overweight, and 1.3 SDS (90th percentile) to detect obesity.

The interrelationships between weight-related anthropometric variables were in general strong and positive. WC was more closely associated with BMI and BMI changes than any of the other variables included, for both sexes and through all ages. Age affected the different interrelationships in a similar pattern for both sexes: being strongest between 7–12 years and weakest among younger children. SH and WSHtR were closer correlated with WC than with BMI, and did not predict changes in BMI better than WC or WHtR.

BMI increments increased slightly during childhood, reached a peak in puberty, followed by a decrease in 14-year-old children. Data from boys and girls were not significantly different within age groups, neither for BMI increments nor for BMI SDS increments. Children with higher BMI had larger BMI increments. Based on annual correlations of the BMI SDS, conditional change in BMI SDS was calculated with a two correlation model. Mean SDS was close to the expected value of zero, and the method covered 94% of the observations within +2/-2 SD.

Conclusions

This study has provided new growth models and references on four weight-related anthropometric variables associated with regional body fat patterns in the Norwegian child population. These references give us the possibility to include markers of regional fat in the evaluation of children as an addition to the BMI evaluation, or as a single evaluation where BMI may be difficult to obtain. The distributions of WC, WHtR, SSF and TSF provide a platform for further studies on regional fat patterns and health risks, as well as for monitoring trends in the future.

Cut-offs in relation to IOTF's BMI criteria, suitable for the studied age span and the present population, could be calculated for WC and skinfolds, but not for WHtR. The cut-offs highlight the values that describe BMI-based overweight and obesity with minimal risk of positive misclassification. The cut-offs in absolute values do not change with a changing prevalence of overweight in the future, but further studies on the association to clinical outcome are needed.

WC has a closer association with BMI than any of the variables included, and mirrors the tendency for greater fat deposit in the central region, seen by increasing BMI due to overweight and obesity. WC may give additional information about health risks especially among moderately overweight children, but further studies are needed to confirm this. In this study using anthropometry SH or related WSHtR did not seem to have any advantages or the potential to add information above WC or WHtR. The weight-related anthropometric variables had a weaker relationship with BMI below six years of age, possibly indicating larger uncertainty in the evaluation of overweight in the youngest age group as compared with older children.

Conditional change in BMI SDS has a potential to be implemented in a computerized growth journal, flagging children with aberrant growth development, and used as a supplement to BMI values.

1.3. List of papers

1. Brannsether B, Roelants M, Bjerknes R, Júlíusson PB.
Waist circumference and waist-to-height ratio in Norwegian children 4–18 years of age: Reference values and cut-off levels. Acta Paediatr 2011;100:1576–82

2. Brannsether B, Roelants M, Bjerknes R, Júlíusson PB.
References and cut-offs for triceps and subscapular skinfolds in Norwegian children 4–16 years of age. Eur J Clin Nutr 2013;67:928–33

3. Brannsether B, Roelants M, Eide GE, Bjerknes R, Júlíusson PB.
Interrelationships between anthropometric variables and overweight in childhood and adolescence. Am J Hum Biol 2014;26:502–10

4. Brannsether B, Eide GE, Roelants M, Bjerknes R, Júlíusson PB.
BMI and BMI SDS in childhood: annual increments and conditional change. Submitted June 2015.

1.4 Abbreviations

AR	Adiposity Rebound
BGS	Bergen Growth Study
BMI	Body Mass Index (kg/m^2)
BIA	Bioelectrical Impedance Analysis
CT	Computerized Tomography
DXA	Dual X-ray Absorptiometry
FM	Fat Mass
FFM	Fat Free Mass
IOTF	International Obesity Task Force
LMS	A statistical method to summarize growth reference curves. L = Lambda (Box Cox power), M = Mu (median), S = Sigma (coefficient of variation)
MRI	Magnetic Resonance Imaging
NIPH	Norwegian Institute of Public Health (in Norway)
OB	Obesity
OW	Overweight
SD	Standard Deviation
SDS	Standard Deviation Score
SES	Socioeconomic Status
SH	Sitting Height
SSF	Subscapular Skinfold
TEM	Technical Error of Measurement
TSF	Triceps Skinfold
WC	Waist Circumference
WHR	Waist/Hip Ratio
WHtR	Waist-to-Height Ratio
WHO	World Health Organization
WSHtR	Waist-to-Sitting Height Ratio

2.0 Introduction

2.1 Background

2.1.1 The overweight epidemic: trends and prevalence from global and regional studies

For many years there has been an increasing prevalence of paediatric overweight and obesity observed globally (1). WHO published a study on the global prevalence of overweight and obesity among preschool children based on WHO standards, using data from 144 countries including trend data from 111 countries, and compared these findings with a similar (but smaller) study ten years previously to summarize the trend (2). The authors estimated the global prevalence of overweight including obesity to be 6.7% in 2010 compared to 4.2% in 2000, and made a prediction about future prevalence as illustrated in Figure 1, assuming a similar increase in years to come.

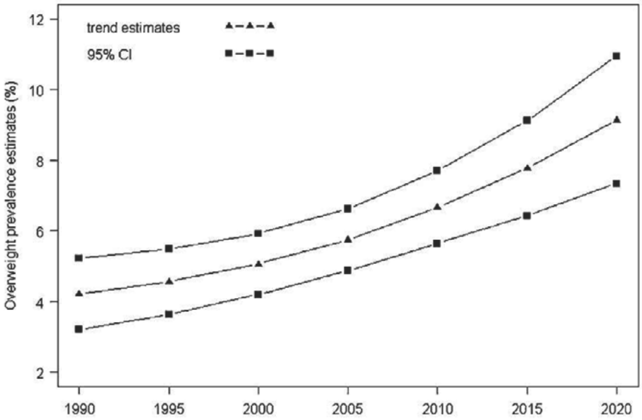

Figure 1. Global prevalence and trends of overweight and obesity among preschool children. Mercedes de Onis et al (2). Reprinted with permission.

In the Global Burden of Disease Study 2013, the global as well as regional and national prevalence of overweight between 1980 and 2013 were estimated for both children and adults (3). In 2013 the overall prevalence of overweight including obesity among children in developed countries was estimated to be approximately 23%. The relative increase was larger in many developing countries, and a majority (in absolute numbers) of the overweight children lived in developing countries. In developed countries, lower socioeconomic status (SES) has been associated with higher rates of overweight, while in developing countries there has been a more variable pattern dependent on the context and the stage of general economic welfare in the society (4).

Several problems may arise when trying to estimate a global prevalence: there may be different definitions of overweight and obesity between studies, data may come from different time periods, the quality of the studies used may be uncertain, estimates may be affected by a few countries with large populations, and there may be variation in children's age groups and stages of maturation. Still, there is no reason to doubt the main conclusion that the increase in the prevalence of overweight and obesity has been pronounced; in some countries the frequency of being overweight has reached the level of the average, and we face an alarmingly high number of very young overweight children.

In Europe there is a north-south gradient: northern European countries have prevalence rates of overweight including obesity of around 15% to 25% for children between 2 and 19 years of age, while the most southern countries, together with the UK and Ireland, have prevalence rates of 25% to 40%, similar to the rate seen in USA (3, 5). A recent trend report from the UK indicated that the rates of overweight among children were stabilizing, especially in the youngest age group (6).

Norway has a population of 5 million people who are fairly widely dispersed. The Bergen Growth Study (BGS), conducted between 2003 and 2006, was based on urban communities only, and reported an overall prevalence according to the International Obesity Task Force (IOTF) criteria of 13.8% among children aged 2 to 19 years of age, with the highest rates among preschool children (17.0%) and the lowest among adolescents (11.7%) (7). Data from the BGS were compared with data from the same county 30 years previously, and showed increasing weight for height as well as increasing skinfold thickness (8). The same trend was demonstrated in the Young HUNT study, which collected data from adolescents mostly living in rural areas in the county of Nord-Trøndelag (9, 10).

The most recent data from Norway comes from the Child Growth Study conducted by the Norwegian Institute of Public Health (NIPH) as part of the

European Childhood Obesity Surveillance Initiative (COSI). In this study the children were restricted to third-graders (aged 8 to 9 years old) from randomly chosen schools across the country, with the study being conducted between 2008 and 2012. The overall prevalence of overweight from this study was 16%, and in this period there was no increase in the prevalence of overweight or obesity, indicating that the increasing prevalence may be levelling off. In this study the prevalence of overweight was higher in small communities compared to large communities. In the same study it was shown that lower maternal educational levels, divorce status among parents, and small communities (rural areas) were associated with a higher prevalence of overweight (11). For the specific age group investigated, the results are in accordance with the findings from the BGS.

Almost all studies commenting on overweight prevalence refer to data on Body Mass Index (BMI). Data from the BGS and other studies on secular changes in waist circumference (WC) and skinfold thickness have indicated larger changes in these variables compared to BMI (8, 12-14). The larger secular increase in WC and skinfold thickness could imply that using BMI exclusively in the evaluation of weight trends might lead to an underestimation in both the increase in fat amount and the health risk. In the Child Growth Study described above, the risk factors (small communities, low education level of mother, and divorce status among parents) were more strongly associated with abdominal fatness, defined by waist-to-height ratio (WHtR) > 0.5, than with general fatness as defined by the BMI criteria (11).

There has been a significant focus on defining important periods and early factors for the development of overweight (15-17). An increasing number of papers report on a ‘tipping point’ at a very early age, indicating that factors early in life play a major role in the later development of overweight (18, 19). The term ‘tracking’ is used to describe the tendency of overweight children to continue being overweight into adulthood (20, 21). Obesity tracking throughout childhood has been shown to be a strong predictor of metabolic risk in adulthood (22, 23). A key target is therefore to achieve effective prevention of overweight from a very early age.

Parents and health-care workers generally underestimate children’s weight, and this is especially evident among the youngest children (24-26). Apart from the wish to have healthy children, our perception is likely to be affected by what we experience as being average in our society. The failure of parents and health-care workers to recognize or accept children’s overweight is of great concern, as both preventive efforts and the successful treatment of overweight children largely depend on parental support. Prevention of childhood overweight must therefore rely largely on public systems, with repeated measurements of the child population to recognize children at risk.

2.1.2 Causes of overweight

Overweight and obesity are principally caused by an energy imbalance, with more energy consumed than expended. The excess energy is stored as fat. A variety of different factors play a role in obesity. Body weight and body composition are influenced by genes, metabolism, behaviour, and environment. Genetic factors have been shown to contribute to 50–90% of the variance in BMI (27), explaining different susceptibilities for developing excess fat. There has been an increased availability and consumption of energy-dense foods with a high fat content and with higher amounts of sugar added (28, 29). The modern human lifestyle leads to less physical activity. Changes in gut flora as a result of environmental factors such as medication, diets, and lifestyle have been documented and are thought to play a role in many diseases, including obesity (30). The interactions between genes and environmental factors are important, where environmental factors may modify genetic expression (31). The environment in a broad sense is affected by politics and decisions involving different sectors such as health, agriculture, transport, food processing, marketing, and distribution (32-34). The overweight epidemic is therefore a multifactorial disease, with individual factors affected by and closely related to conditions in our environment.

2.1.3 Consequences of childhood overweight: health risks and economic burden

There are numerous complications associated with childhood obesity, and it has the potential to affect all organ systems. Cardiometabolic risk has been thoroughly documented by several authors (35, 36), and different review papers have summarized the overall health risk (6, 37-40). Early childhood obesity also has the potential to adversely affect normal development and maturation during childhood. An acceleration of maturation has been documented (41, 42), as well as increased growth (43), although final height is usually not affected. Orthopaedic complaints have been described as more common in obese children (44). Several papers have shown that overweight and obesity during childhood influence the mortality and morbidity rates in adulthood (40, 45). Apart from physical morbidity, a number of psychological consequences have been described (39), including systematic discrimination, reduced self-confidence, effects on social life, reduced school performance and hence future prospects, and ability to self-support.

The economic burden is enormous, covering medical costs for diagnostics and treatment of diseases and complications connected to obesity, but also indirect costs related to absence from work, inability to work over time, early retirement, and production loss (46, 47).

2.2 Definitions of overweight and obesity in childhood

For many years weight in relation to height (kg/m) was used to define overweight and obesity in the paediatric population. The former Norwegian growth reference published in 1983 included weight-for-height charts (48). There is now an international consensus on the use of body mass index (BMI = kg/m^2) as a standard measure of overweight and obesity (49-51). Table 1 shows the accepted definition of overweight and obesity in adults. There is a continuous increase in health risk and mortality as BMI increases, but the cut-offs mark the zones where a steeper increase in risk was observed (52). In some Asian countries cardiometabolic risk factors have been seen at lower levels of BMI than 25 kg/m^2 (53, 54), and the WHO has recommended that these countries should consider lower cut-off values for overweight and obesity in the adult population (55).

On the initiative of the IOTF, an international definition of paediatric overweight and obesity was constructed in 2000, based on the adult definition but with sex- and age-adjusted cut-offs for children (56). Cross-sectional growth data from six countries were used, and for each of these surveys centile lines were constructed so that the centiles passed through the adult cut-off points for overweight (25 kg/m^2) and obesity (30kg/m^2) by the age of 18 years. The six curves were finally averaged to common BMI lines for children aged 2–18 years of age for overweight and obesity. Figure 2 shows the resulting centiles for overweight and obesity for the six countries respectively, as well as the final common international cut-off points. BMI charts using the same cut-off values have also been developed for Norwegian children (57).

The BMI definition is attractive because of its simplicity, and because a universal definition makes it possible to compare different populations. On the other hand, BMI cannot distinguish between the different tissues that together constitute body composition, and body composition is crucial regarding health risk. As will be discussed in the following chapters, body composition changes considerably during childhood, and BMI changes during childhood may therefore be difficult to interpret in terms of health risk. Although universally accepted as the diagnostic tool of overweight, many authors have discussed the shortcomings of BMI and the need for alternative or additional tools that better reveal the amount of fat mass and the associated health risk (58-60).

Table 1.
BMI classification of overweight and obesity in adults

Overweight	≥ 25 kg/m²
Obesity	≥ 30 kg/m²
Obese class I	30.0–34.9 kg/m²
Obese class II	35.0–39.9 kg/m²
Obese class III	≥ 40 kg/m²

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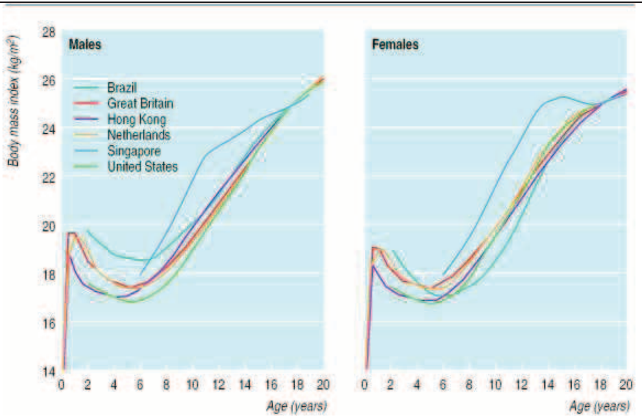
<tr><td>A. Centile lines for overweight by sex</td><td>
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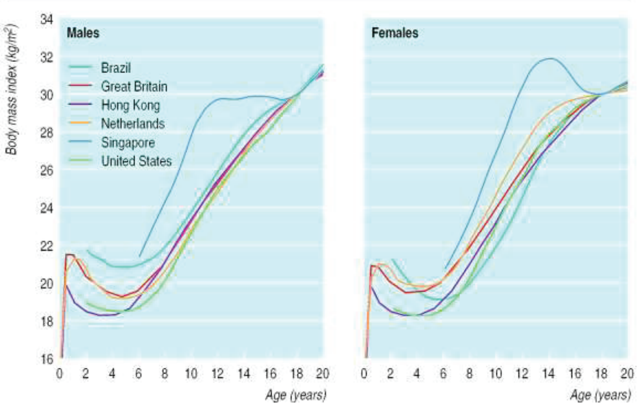
<tr><td>B. Centile lines for obesity by sex</td><td>
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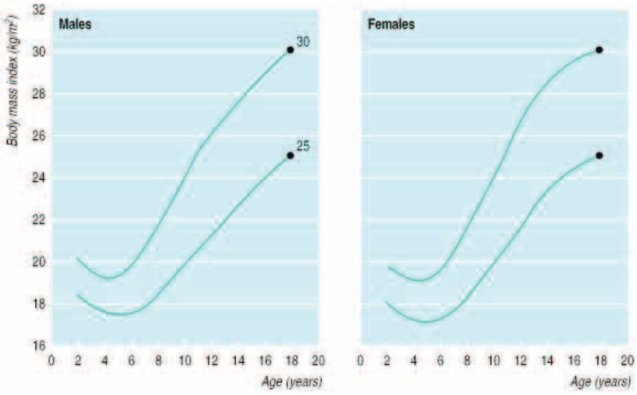
<tr><td>C. International cut-off points for overweight and obesity by sex</td><td>
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</table>

Figure 2. BMI centile lines for overweight and obesity. Figures 2A and 2B show BMI centile lines from six countries that pass through the adult cut-off points for overweight (25 kg/m²) and obesity (30kg/m²) by the age of 18. Figure 2C shows the averaged lines for overweight and obesity by sex that are recommended as international cut-offs for children. Cole et al BMJ 2000 (56). Open access.

2.3 Growth charts

Evaluation of children's growth is one of the most important and basic skills in paediatrics worldwide (61). Growth has the potential to mirror a child's health and well-being, as well as the society surrounding the child (62). It is a dynamic process, based on the child's genetic growth potential and affected by a large number of internal and external factors that interact in different ways (63). Aberrant growth may be a sign of inadequate nutrition, disease, or an unfavourable environment. References reflecting normal growth are fundamental for the detection of abnormal growth (64, 65). Environmental factors may affect growth in both positive and negative directions and give rise to secular trends over time. The positive secular trends in height (66) and BMI (67-69) have been levelling off in many countries.

The term 'growth reference' is used to describe how children in a certain population grow, while the term 'standard' has been used lately to describe how children should grow if they are provided with optimal conditions (61). It follows from these terms that a reference will need to be updated according to secular trends, while a standard should describe optimal growth and hence is not dependent on trends. In 2006 WHO published a growth standard for children from 0–5 years of age, thought to represent the optimal growth for children worldwide (70). Several later studies compared the WHO standard with national references and found large deviations between the WHO standard and the national references; among these were Norway and Belgium (71). This indicates that growth is affected by ethnicity, and challenges the concept of global standards for anthropometric variables.

Growth curves based on population references are used extensively both in the preventive health-care system and in clinics to evaluate a child's linear growth and weight development (61, 72). Most of these are cross-sectional growth references that specify the distribution (mean and variability) of a measurement in the reference population over a range of ages (or on some other basis, e.g. height). The distribution is summarized either as centiles of the distribution or as selected standard deviation scores (SDS), and is presented as smoothed curves. The size (e.g. height) of a particular child is plotted on the reference curve and may tell whether that child is within normal limits for her sex and age in the reference population. Usually the limits of normality are set between -2 and +2 SD lines, corresponding to percentiles 2.3 and 97.7 and covering 95.4 % of the population. If the data are normally distributed, like height for instance, it is easy to calculate the population distribution, but if the data are skewed, e.g. data on weight and waist circumferences, more advanced statistical methods that can handle the skewness are required (64). One of the most widely-used methods today is the LMS method (73). It is common practice to use the term ‘growth curve’, although a reference based on a cross-sectional study does not measure growth, but rather size.

To assess growth over time in an individual, longitudinal data are necessary. Based on two or more measurements over time it is possible to evaluate the increments and velocities, and compare these with velocity centiles (65, 74). Detection of abnormal changes in anthropometric variables, e.g. height, may be an early sign of disease (75-77).

2.4 Measures of body composition

The relative size and contribution of different body components and tissues may be described as body composition. Usually one refers to the percentage of fat, muscle, skeletal, and water components. Body composition is both age- and sex-specific, and it changes during childhood. Girls have more subcutaneous fat and a higher amount of total body fat, while boys have higher muscle and skeletal mass, but also tend to accumulate visceral fat more easily than girls. The changes in body composition during childhood are most prominent during puberty, resulting in the typical male-female phenotypes (63). While linear growth stops after puberty, changes in body composition continue throughout an individual’s life.

Ethnic background affects body composition. When comparing Asian and black adults with white adults at equivalent levels of BMI, Asians have more body fat, while black adults have less body fat than whites (78, 79). Similar differences have been described in childhood (80).

With an increasing prevalence of overweight among children, there has also been an interest in defining body composition in children, and consequently in techniques suitable to measure the different tissue components in children (58, 81-83). Different techniques to measure body composition and excess fat are described by Sweeting (84) and Pietrobelli (81) among others, and are summarized in Table 2. Although there are many available techniques for calculating body composition, many of these are time-consuming and expensive. With regard to measuring fat, anthropometry, using BMI, WC and skinfolds, is therefore still the most widely-used alternative for screening purposes or for large field studies such as the BGS. Anthropometric assessments have varying but in general larger measurement errors than more sophisticated methods (85), and a calculation of technical error of measurement (TEM) is often used to describe measurement reliability and accuracy in field studies (86).

Wells and colleagues compared body composition in normal weight, overweight and obese children using a four-component model, calculating fat mass (FM), fat-free mass (FFM), hydration, and minerals (87). With increasing weight there was an increase not only in FM, but also in FFM and minerals. With increasing BMI, FM showed a steeper increase than FFM and minerals, and FM increased to a larger extent in the truncal region, while FFM increased equally in the truncal region and in the extremities. Although obese children had a larger percentage of FM in general, and FM accounted for most of the excess weight for all groups, this study demonstrated a large variability in body composition for a given BMI value in both obese and control children. This indicated that a normal BMI does not necessarily mean a healthy body composition. The same study showed that obese children were taller than normal weight children. Later studies have confirmed that the height difference is greatest at puberty and parallels advancement in skeletal maturity, indicating advanced maturity in obese children compared to normal weight children (88, 89). There is no difference in final height between obese and normal weight children. Earlier maturation and puberty linked to obesity have been confirmed by several studies (90, 91). Overweight therefore affects body composition through the excess of fat tissue in itself, but also through the effects of the excess energy and fat tissue on other processes such as maturation.

Table 2. Methods to measure body composition and fat in children

General Principle	Method	Comments on use	References
Density-based methods	Hydrodensitometry (UWW) and Air Displacement (ADP)	Relative proportions of fat and fat-free mass can be estimated from density. Time-consuming, limited to research.	(92, 93)
Scanning	CT and MRI (computerized tomography and magnetic resonance imaging)	Cross-sectional imaging. Precise measures of body composition and regional distribution of fat mass. Used to evaluate effectiveness of anthropometric measurements. Expensive, high radiation exposure with CT. Limited to research.	(38, 94-96)
	DXA (dual-energy X-ray absorptiometry)	May calculate both total and regional body composition, including fat mass, fat-free mass and bone mineral density. Low radiation. Used to evaluate effectiveness of anthropometric measurements. Limited to research and/or specialized obesity clinics.	(36, 97, 98)
Bioelectrical impedance methods	BIA (bioelectrical impedance analysis)	The resistance between conductors provides a measure of body fat. Portable equipment makes this an alternative in both obesity clinics and field studies. British body fat reference curves based on this technique.	(96, 98, 99)
Anthropometry	WC (waist circumference) Skinfolds WHtR (waist to height ratio)	Offers direct measurements of different body parts, non-invasive, easily accessible and does not require expensive equipment. WC reflects both total and abdominal fat. Skinfolds measure subcutaneous fat at different sites, and may be used in equations to predict body fat. Waist-to-height ratio has been suggested as a rapid screening method for excessive abdominal fat.	(94, 100-102)
Various	Lipometers	Measures subcutaneous fat at predefined sites. Some studies in childhood, but restricted use. Requires special equipment and software.	(103-105)
	Multi-component models	Different techniques are combined depending on how many components lean mass is divided into. Some would regard the four-component model as the most accurate, giving values on fat mass, water, protein, and minerals. Requires advanced equipment. Limited to research.	(83, 106)

The table is modified from Sweeting et al 2007 (84).

2.5 Weight-related anthropometric measurements

2.5.1 BMI, overweight, and obesity

During normal growth in childhood there is an increase in BMI as a result of growth in all tissues. BMI has a curvilinear shape with age, which is why a simple cut-off cannot be used to define overweight or obesity in childhood. It was first suggested that the 85th and 95th centiles of BMI charts should be used to define overweight and obesity respectively (107, 108). Later, sex- and age-specific cut-offs that were statistically equivalent to the adult cut-off values were suggested by IOTF (56).

Maynard et al used data from the Fels longitudinal study to describe body composition in relation to BMI (109). They found that the normal annual increase in BMI during childhood was generally attributed to greater increases in lean mass than in fat mass. The relative contributions to annual changes in BMI were both age- and sex-dependent – e.g. in girls the increases in total body fat (TBF) contributed to a larger extent than in boys. Demerath et al investigated changes in BMI percentile in relation to changes in body fat and lean body mass during childhood (110). BMI was quite similar between the sexes, but when the BMI was divided into a Fat Mass Index (FM, kg/m²) and Fat-Free Mass Index (FFM, kg/m²) it differed between genders. While the FFMI had a linear relationship with BMI percentiles, the FMI and percentage body fat had more complicated relationships with BMI percentiles, and were dependent on age, sex, and level of BMI percentile. The conclusion was that changes in BMI percentiles during childhood do not necessarily reflect changes in adiposity over time. A study of body fat in British children showed marked differences in body fat between boys and girls at puberty, which was not apparent on existing BMI curves (99). It has also previously been demonstrated that there are large differences in fat mass for a given BMI within the same sex and age group (111); an example is shown in Figure 3.

The accuracy of BMI in detecting body fatness depends on the degree of body fatness. The accuracy increases with increasing body fat, but among thin or moderately overweight children differences in BMI may reflect differences in lean mass as well (112).

Ethnic differences in the amount of fat mass at the same level of BMI have previously been mentioned (80, 113). In addition, BMI has limitations when applied to children with different conditions that might affect body composition (114). We have seen similar changes in a study of children with cerebral palsy, where children with the most serious disease had more fat mass compared with children with the same BMI but milder disease (115). If dietary advice is primarily based on BMI, the advice may be insufficient and not to the benefit of the patient.

This means that BMI, although positively correlated with total body fat and widely used to diagnose overweight and obesity, does not distinguish between fat mass and lean mass. Annual changes in BMI in childhood may be difficult to interpret in terms of health risk, as there is large variability in fatness for a specific BMI value, depending on sex, age, maturation stage, individual factors, ethnicity, and general health condition. Facing the high prevalence of overweight and the potential health risk for our children, BMI diagnostics alone may not be sufficient to meet this challenge.

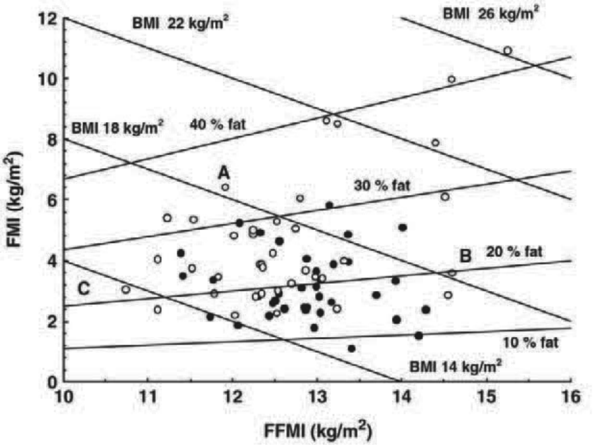

Figure 3. Hattori graph for children aged 8 years (light blobs: girls; dark blobs; boys) showing fat mass adjusted for height (fat mass index; FMI) v. lean mass adjusted for height (fat-free mass index, FFMI). The individuals A and B represent two girls with similar BMI (approximately 18 kg/m^2), but with A having twice the FMI of B. Individuals B and C have similar percentage fat, but very different BMI and FFMI. Wells et al (116). Reprinted with permission.

2.5.2 Fat patterns and health risk

For a long time it has been recognized that there is a link between distribution of body fat and health risks, independent of the association between similar health risks and general obesity (117, 118). Since the 1990s it has been usual to distinguish between android and gynaecoid fat patterns, also called the apple and pear forms. This refers to patterns with predominantly abdominal fat deposits (apple), or fat deposits in the lower part of the body (pear). A lot of studies emerged demonstrating a larger risk of insulin resistance, type 2 diabetes, and cardiometabolic risk factors connected to the predominantly abdominal (or central) fat pattern (119-121), and conversely a better metabolic profile associated with large hip and thigh circumferences (122, 123). Detailed descriptions of the mechanisms thought to be essential for this difference are beyond the scope of this introduction, but they have been summarized in a recent review (44). Different assessments were suggested to estimate fat distribution; initially waist/hip ratio (WHR) was used, but later WC or WHtR became more usual. Studies concluded that WC and WHtR seemed to be better markers of increased metabolic risk in adults when compared with BMI (124). Later studies have confirmed that a large WC is related to increased mortality in adults, independent of BMI (125, 126). In a comparison of anthropometric indices and BMI in terms of the ability to predict abdominal fatness, it was concluded that WC in general seemed to be the best predictor in adults (95). Later studies have been conducted in children and have confirmed similar findings (see below).

Several authors have found that the sum of skinfolds or the use of skinfold measurements in specific equations, are associated with adverse health risk factors, but it does not seem that skinfold data perform *better* than BMI in predicting adverse health risk (127, 128).

2.5.3 Waist circumference and related ratios in children

WC is a simple, inexpensive, and non-invasive measure of central fatness. A high correlation between WC and truncal adiposity in children has been confirmed in studies using MRI (94), CT imaging (95), and DXA (97). Different authors have found stronger associations between central adiposity measured by WC and health risk factors such as adverse lipoprotein profile, insulin resistance, and high blood pressure in children, than between BMI and adverse risk factors (36, 129-133). Other studies have found that among the fattest, the ability to predict adverse health risks in children is quite similar between WC and BMI (134, 135). Several studies have demonstrated a larger secular increase in WC than in BMI for children (12, 136, 137), indicating a possible higher adverse health risk than what is detected by BMI trends alone. Reference values and percentiles for WC as well as for WHtR have been developed for children in several countries (138-145).

There is no consensus on how to define cut-off values for WC in childhood. In adults there are upper action levels of 102 cm for men and 88 cm for women that are associated with increased cardiovascular and metabolic risk (146). Regarding children, some studies have suggested cut-offs based on associations between percentiles and cardiovascular and/or metabolic risk (131, 147). Percentiles are prevalence-dependent, and hence the absolute value of the specific percentiles may change over time. Others have suggested that cut-offs should be derived from existing BMI criteria for adults; for example, Virani et al suggested the derivation of sex- and age-specific cut-off values based on centiles analogous to adult Asian Indian cut-off values (139), while in the Netherlands cut-offs were based on the Western BMI criteria with > 1.3 SDS as a cut-off for overweight and > 2.3 SDS as a cut-off for obesity (138). As ethnicity affects body composition *and* health risks, it is necessary to have population-based (national) cut-offs based on clinical trials as well as national references.

WHtR has been suggested as a useful clinical parameter for evaluating central adiposity in children (148). Some authors have found WHtR to be a better predictor of cardiovascular disease risk in childhood than BMI (129, 149), although others could not detect this difference (150). In adults a cut-off of 0.5 has been proposed to indicate excessive fat storage in the truncal region and therefore an increased health risk (151, 152). Several other authors have argued for the same cut-off in children (100, 153). It is not clear whether this is applicable to the entire child population, as some authors have found this cut-off appropriate also in preschool children(154), while others have argued against this (140), suggesting a need for reference charts. In Norway no national reference data on central fat patterns are available.

2.5.4 Subcutaneous skinfolds in children

Skinfold thickness is used to measure subcutaneous fat and offers a possibility to measure fat accumulation at specific sites. Like WC, this is an easy, inexpensive, and non-invasive method, but it requires a skinfold calliper and experienced observers to avoid measurement errors. It may be difficult to measure skinfolds in obese children due to the massive fat accumulation beneath the skin. Skinfolds are well correlated with total body fat (155, 156), although some studies could not detect additional information about excess body fat beyond BMI alone in very overweight children (157, 158). Triceps, biceps, and subscapular skinfolds are most often used in studies of children, and national references for skinfolds have been developed in different countries (159-161).

Different equations have been suggested to predict body composition from skinfolds. Five different equations for skinfolds were validated by Reilly et al using underwater weighing of healthy prepubertal children (102). Their conclusion was that the equations were associated with large random errors, which made skinfolds less suitable as a measure of body fatness but probably more valuable as *indices* of body fatness. Later studies have emerged investigating the usefulness of skinfolds and different equations in children with diseases that affect body composition, demonstrating more promising results for these specific groups (115, 162, 163).

Skinfold measurements have also been used to monitor excess weight on a population basis (8, 14, 164). The BGS demonstrated a secular increase in skinfold thickness from the 1970s to 2003, which exceeded the corresponding increase in weight-for-height (8). While mean skinfold thickness increased in all percentiles, the lower percentiles of weight-for-height were less affected. This showed that the amount of subcutaneous fat increased for all children, a fact that was not detected in the lower percentiles of the weight-for-height index. A marked secular increase in skinfold thickness among Norwegian children indicated that it was time to update the skinfold reference, but also demonstrated a need for cut-offs in relation to excess weight that were not dependent on secular trends.

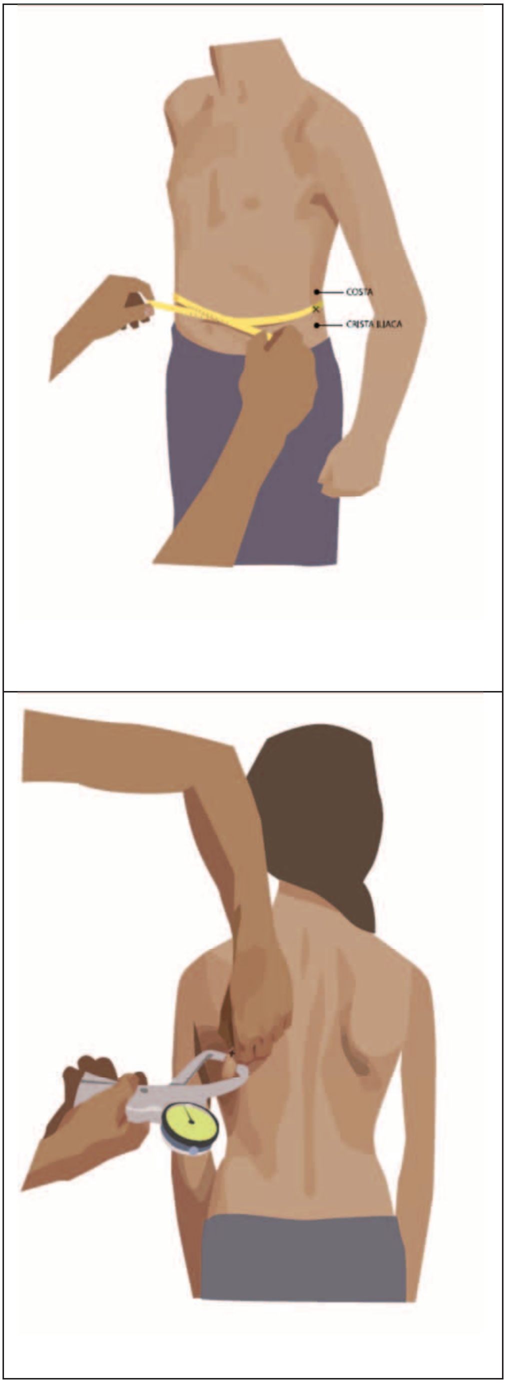

Figure 4.

a) Measurement of waist circumference
b) Measurement of subscapular skinfold

2.6 BMI and BMI SDS increments

Repeated measurements of anthropometric variables give more specific information about changes over time. If the expected change in a variable over a specific time is known, an abnormal change may serve as guidance in diagnostics, as has been suggested for height in relation to short stature (75) and Turner syndrome (76).

In relation to overweight, the detection of an abnormal change in BMI could be important for preventive purposes, with the potential to detect unexpectedly large changes in BMI even before overweight has established. As mentioned in section 2.5, BMI increments and BMI centile crossing are difficult to interpret in terms of health risk, as the relation to body composition is both sex- and age-dependent (109, 110). A US Expert Committee suggested that an annual increase of 3–4 kg/m^2 in BMI probably reflects a rapid increase in body fat (165). A study from Japan used correlations between measurements to study the variance of changes in BMI SDS, and defined excess BMI gain in terms of delta SDS (166). Annual changes larger than 2 SD of delta SDS were suggested to be indicative of a rapid increase in body fat among Japanese children. When converting the SDS to actual BMI values, the BMI changes were somewhat lower in this study than in the recommendations from the US: 1–2 BMI units/year for younger children, and 2–3 BMI units/year for older children. Both of these recommendations aimed to define a rapid increase in body fat based on abnormal changes. The study from Japan used SDS, which implies an adjustment for sex and age. As a result the mean SDS in a sample of subjects is close to 0, with a standard deviation (SD) close to 1. The method used in this study was velocity on the SDS scale, which assumes that the expected increment of a particular child should maintain the child on the same centile (74). This method does not adjust for regression to the mean and may be biased.

Cole suggested another method, first proposed by Healy (167): conditional velocity or change (74), where the second measurement (SDS) is adjusted for the first measurement (SDS). This method accounts for regression to the mean. Because the second SDS is adjusted for the first SDS, it is not assumed that the second SDS is the same. The method is therefore not biased.

To be able to calculate conditional gain, a matching growth reference to convert the measurements to SD scores is mandatory, and the correlations between the time points must be known. Based on this method, conditional changes in BMI SDS could give information about unexpectedly large changes in BMI SDS compared to a child’s peers, without pretending to give information about changes in body fat. As far as we know conditional changes in BMI SDS have not been published before. Conditional growth based on the correlation between longitudinal measurements has been validated for weight in the UK (74), and for length, height, weight and head circumference in Belgium (168)

3.0 Aims of the study

The overall aim of this work was to study the weight-related anthropometric variables – WC, WHtR, TSF and SSF – in the context of the increasing prevalence of overweight among children. The intention was also to provide a platform for further studies of fat distribution patterns and health risks among children, and for monitoring changes in fat distribution over time.

Specific objectives

1. Weight-related anthropometric traits beyond BMI

- To develop growth models and estimate national references for the weight-related anthropometric traits – WC, WHtR, and TSF and SSF – from a representative sample of healthy Norwegian children.

- To study cut-offs for overweight and obesity in relation to BMI for WC, WHtR, TSF, and SSF.

- To study the interrelationship between BMI and other weight-related anthropometric measures at different ages in childhood.

2. BMI increments and conditional gain

- To study one-year incremental data on BMI. Further, to evaluate conditional change in standardized (SDS) BMI based on a correlation model, as an alternative method of evaluating BMI changes.

4.0 Materials and methods

4.1 The Bergen Growth Study

4.1.1 Summary of the BGS

The BGS is a cross-sectional study with the measurement sampling taking place between November 2003 and December 2006 in the city of Bergen. Bergen is the second largest city in Norway and had 237,430 inhabitants on 1 January 2004. The study protocol was approved by the Regional Committee for Medical Research Ethics and the Norwegian Data Inspectorate. Only children with a signed letter of informed consent from one parent were included. For children over 12 years, the letter was signed by both parent and child.

The new national growth references for Norwegian children are based on the data collected in the BGS, and detailed information on study design, assessments, and quality was provided earlier (57, 169, 170).

A brief summary of the BGS is presented in Table 3.

4.1.2 The present study

For the present study different samples from the BGS were used. Table 4 gives a summary of the samples included and the purpose of the papers. Only healthy subjects were included. About 1% of the children were excluded due to chronic diseases that might affect growth. Children outside +/- 5 SDS were excluded as these were thought mainly to represent measurement or registration failure, and/or they might affect the curves too much. Children with a measure of +/- 4 SDS were checked individually and only if the value was obviously an error the child's measurement was excluded. For WC, WHtR, and skinfolds, there were less than 5 measurements excluded per sex.

Table 3. A short summary of the Bergen Growth Study (BGS) 2003–2006.

Children randomly selected from:	Well baby centres	Kindergartens	Schools (1st–10th grade)	Schools (11th–13th grade)
Number	8	34	*19	5
Age	0–6	1–5	6–15	16–19
Participation rate	98%	57%	6–12y: 69% 13–15y: 53%	45%

Total number included: 8299 children 0–19 years of age
Sex: 4264 boys, 4034 girls
Ethnicity (one or both parents) outside Nordic countries: 11%

Elements of the study:

One anthropometric assessment covering up to 10 variables dependent on age (e.g. head circumference only measured up to 6 years) by trained nurses (n = 13) and one paediatrician.

*Seven of these schools were randomly chosen for a second assessment of weight and height one year later.

Questionnaires: sent to 7472 children. 67% of the questionnaires returned.

Table 4. Overweight and obesity in children: a study of weight-related anthropometric variables in childhood - The study at a glance

	Sample size (boys/girls)	Age in years	Purpose of the study
Paper 1	5725 (2945/2780)	4.00–17.99	Calculate references for WC and WHtR using the LMS method and cut-offs in relation to overweight and obesity by ROC analysis.
Paper 2	4606 (2325/2281)	4.00–15.99	Calculate references for SSF and TSF with the LMS method and cut-offs in relation to overweight and obesity by ROC analysis.
Paper 3	4576 (2309/2267)	4.00–15.99	Study the interrelationships between weight-related variables during childhood by means of correlation and multiple regression analyses of standardized scores.
Paper 4	1167 (576/591)	6.00–14.99	Study annual increments of BMI and evaluate conditional change in BMI SDS as an alternative method to interpret BMI changes.

4.2. Statistical methods – LMS

General statistical methods in this study are described in the individual papers. Two of the most important methods for this work, the LMS method and the ROC curves, are described in more detail below.

The LMS method

The LMS method is a widely-used method for growth curve estimation (72, 73, 171). Cross-sectional growth reference curves specify the distribution of a measurement (e.g. height, weight, waist circumference, or skinfolds) in a reference population over a range of ages. The distribution is summarized either as centiles of the distribution or as selected standard deviation scores (SDS). If data are normally distributed (as for height and head circumference) this is usually a simple calculation, but for weight-related anthropometric variables (weight, waist circumference, skinfolds) this is not the case, since the data are skewed. To obtain curves that are practical to use it is necessary to apply methods to deal with the skewness. The LMS method provides normalized growth centile standards and deals with the skewness by means of a power transformation. The power transformation can shrink one tail of the distribution and stretch the other one. Age is treated as a continuous variable, and the distribution of the measurements is summarized using three smoothed age-related curves. The M (median) curve is calculated from the mean after the data have been normalized with a Box-Cox transformation. The S-curve (SD/mean) represents the coefficient of variation of the measurement as it changes with age. The L-curve is a description of the skewness by demonstrating the Box-Cox power transformation needed to convert the data to a normalized distribution at each age. By combining these curves, it is possible to derive a set of centile or SDS values. Smoothing parameters of equivalent degrees of freedom ('edf' values) determines the degree of smoothing. There are different quality tests available in the system (Q-tests – goodness of fit test, and normal quantile plots).

ROC curves in the evaluation of cut-offs

Receiver operating characteristic (ROC) curves may be used in the evaluation of a particular test to define the usefulness of that test. They can also be used to select a cut-off value for a test (172-174). The method requires a reference or 'gold standard' to compare the test against. ROC curves have been used extensively in the evaluation of anthropometric measurements against other methods, for instance DXA (97). Sensitivity (true positive) and specificity (true negative) are calculated for a range of different cut-off points against the gold standard. When sensitivity for the chosen cut-offs is plotted against the rate of false positive (1-specificity)in the ROC curve, it is possible to identify the optimal point where the misclassification is minimized. Usually the optimal point would be the point closest to 1, or the upper left corner on the ROC curve. However, the cut point may deliberately be chosen differently; for instance, in a population screening test the cost of false positives may have a larger impact than the cost of false negatives, and hence the cut-off is chosen in favour of a high specificity with potential loss in sensitivity. The purpose of the test may therefore change the cut-off values. The accuracy of the ROC analysis also depends on the quality of the reference or gold standard used.

In the present study we used the IOTF's BMI cut-offs for overweight and obesity as gold standards. We detected the theoretical best value (upper left corner) for the different variables used, but we also suggested shifted cut-offs to minimize the rate of false positives. As a screening method the shifted cut-offs that minimize the rate of false positives would be preferred.

5.0 Summary of Results

5.1 Weight-related anthropometric traits beyond BMI (Papers 1–3)

5.1.1 Waist circumference and waist-to-height ratio in Norwegian children aged 4–18 years: reference values and cut-off levels (Paper 1)

The first paper described the growth models and current distributions of WC and WHtR in a sample of healthy Norwegian children representative of the Norwegian child population, and analysed cut-off values in relation to overweight and obesity.

Data from 5725 children aged 4–18 years were analysed. The prevalence of overweight (including obesity) was 14.2% in girls, for obesity alone 2.6%. Corresponding prevalence for boys was 13.4%, and 2.3%.

Reference curves were fitted with the LMS method and percentiles presented. There was a strong positive correlation between WC and BMI ($r = 0.907$, $p < 0.01$) and a moderate positive correlation between WHtR and BMI ($r = 0.397$, $p < 0.01$) for the whole sample. Mean WC increased with age, with significantly higher values for boys at almost all ages. Mean WHtR decreased with age until early adolescence and thereafter increased slightly towards adulthood. For WHtR, differences between the sexes were neither consistent nor statistically significant. The WCs of Norwegian children were in the lower range compared with other European countries.

Table 5 shows some cut-off values analysed for WC with corresponding sensitivity and specificity.

Using a similar strategy, no single cut-off for WHtR could be detected that was appropriate for the whole age range. Optimal cut-off was largely dependent on age group for both overweight and obesity, and below 6 years of age no suitable overweight cut-off could be defined. Table 6 shows the results of the 0.5 cut-off recommended in adulthood (‘keep your waist to less than half your height’).

Table 5. Results of ROC analyses of waist circumference to detect overweight and obesity, all ages together		
Cut-off value SDS	**Sensitivity**	**Specificity**
Overweight		
0.8	88.9	90.2
0.9	85.3	92.5
1.0	78.5	94.3
1.2	67.1	97.0
1.3	61.4	97.8
Obesity		
1.2	98.6	90.3
1.4	97.8	93.4
1.6	94.9	96.0
1.7	89.9	96.8
2.3	38.9	97.8

The suggested cut-offs are marked in blue.
The cut-offs suggested from the Netherlands are included (1.3 for overweight, 2.3 for obesity)

Table 6. Sensitivity and specificity of the 0.5 cut-off for waist-to-height ratio in different age groups in the BGS study*				
	Overweight		**Obesity**	
Age	**Sensitivity**	**Specificity**	**Sensitivity**	**Specificity**
< 6	48.7	94.1	63.6	90.1
≥ 6–18	34.3	99.7	87.3	97.1

Therefore, in relation to the IOTF’s BMI definition of overweight and obesity we could define one cut-off for WC suitable for use between 4–18 years or age, but none for WHtR. The cut-offs for WC that minimized the rate of false positivity with acceptable sensitivity were 1.0 SDS (close to the 85th percentile) to detect overweight, and 1.6 SDS (close to the 95th percentile) to detect obesity.

**Erratum:* Note that in Paper 1 there is an error on p 4. For further description see section 10.0 (Errata) p 74.

5.1.2 References and cut-offs for subscapular (SSF) and triceps (TSF) skinfolds in Norwegian children aged 4–16 years (Paper 2)

The second paper similarly described the growth models and the distributions of SSF and TSF in a sample of healthy Norwegian children, and analysed cut-off values in relation to overweight and obesity.

Data from 4606 children aged 4–16 years were analysed. Reference curves were fitted using the LMS method and percentiles presented. In general the mean values for skinfolds increased with age. Skinfolds were significantly larger for girls than for boys at all ages. Both skinfolds had a high discriminatory power to detect overweight and obesity as defined by the IOTF. Table 7 shows some cut-off values for both skinfolds with corresponding sensitivity and specificity.

Table 7. Results of ROC analyses of skinfolds to detect overweight and obesity, all ages together

Cut-off value SDS	**SSF**		**TSF**	
Overweight	**Sensitivity**	**Specificity**	**Sensitivity**	**Specificity**
0.8	83.5	87.9	79.7	87.3
0.9	80.4	90.3	75.7	89.8
1.0	75.9	92.2	70.0	91.7
Obesity				
1.2	94.8	88.7	89.8	89.4
1.3	91.3	90.3	86.4	91.4
1.4	88.7	91.9	79.7	93.2

The suggested cut-offs are marked in blue

It was possible to define one cut-off for both skinfolds suitable for use in those 4–16 years of age in relation to overweight and obesity. The cut-offs that minimized the rate of false positivity were 1 SDS (close to the 85th percentile) for overweight, and 1.3 SDS (90th percentile) to detect obesity.

5.1.3 Interrelationships between anthropometric variables and overweight in childhood and adolescence (Paper 3)

In the third paper data from 4576 children aged 4–16 years were used. Anthropometric variables, including BMI, height, sitting height (SH), WC, WHtR, waist-to-sitting-height ratio (WSHtR), SSF, and TSF, were transformed to standard deviation scores (SDS) and studied using correlation and multiple regression analyses.

The correlations between BMI SDS and the other standardized variables were in general strong and positive. WC SDS and WHtR SDS showed the strongest correlations with BMI SDS for all ages and in both sexes. A model with all seven anthropometric variables adjusted for age group and sex explained 81.4% of the variation in BMI SDS.

We found that age group, but not sex, contributed significantly to amount of explained variation in BMI SDS. For all variables the correlations were weakest in the youngest age group and highest between 7 and 12 years. When adjusted for all other variables, WC SDS contributed most to the variation in BMI SDS (b = 0.467, CI (0.372, 0.562)) regardless of sex and age. SH and WSHtR were more closely correlated with WC than with BMI, and did not predict changes in BMI better than WC or WHtR, independent of age.

5.2 BMI and BMI SDS during childhood: annual increments and conditional change (Paper 4)

In Paper 4 data from 1167 healthy children (576 boys, 591 girls) aged between 6 and 14.99 years were analysed. The data involved two measurements of height and weight with approximately one year between the measurements. The BMI was calculated and converted to SDS with the LMS method using national BMI references (175).

BMI increments increased slightly with minor variations during childhood, reaching a peak in puberty followed by a decrease in older children. Data from boys and girls were not statistically different within age groups for either BMI increments or BMI SDS increments, with one exception (BMI increments at 8 years of age).

ΔBMI depended significantly and positively on sex, height, and BMI by first measurement, while weight influenced ΔBMI negatively. For ΔBMI SDS, only the initial BMI SDS remained significant with a positive influence in the final model.

Based on annual correlations of the BMI SDS at the first and second measurements (Table 8), a two correlation model was developed according to two age groups: for 6–11 years r = 0.95; and for 12–14 years r = 0.92. When calculating the conditional gain in BMI SDS using this model, the mean SDS was close to the expected value of zero in a normal distribution (0.11, SD 1.02, n = 1167), with 3.2% (2.3–4.4%) of the observations below -2 SD and 2.8% (2.0–4.0%) above +2 SD. This two correlation model covered 94% of the observations between +2/-2 SD. A three or higher correlation model did not improve this validation study.

Table 8. Pearson Correlation coefficient (r) between two measurements of BMI SDS

Truncal age	Number	r
6	135	0.945
7	154	0.951
8	164	0.947
9	144	0.961
10	156	0.960
11	126	0.951
12	66	0.920
13	126	0.916
14	105	0.919

All p < 0.001
Boys and girls counted together

6.0 Discussion

6.1 Discussion of results

6.1.1 Weight-related anthropometric traits beyond BMI

1. National references for WC, WHtR, SSF, and TSF

Abdominal fat deposit is connected to larger health risks than subcutaneous fat pattern (119, 176, 177), and the prevalence of abdominal obesity has been increasing for children (12, 13). Several variables have proven to give more specific information on fat distribution and health risks than BMI, among them WC, WHtR, (126, 129, 133, 178), and skinfolds (155, 156). Our first objective was therefore to provide new (WC, WHtR) and updated (skinfolds) information on anthropometric variables connected to regional fat patterns in the Norwegian child population.

Papers 1 and 2 provide new references for WC, WHtR, SSF and TSF. WC was higher for boys than for girls, while skinfolds showed the opposite pattern (138, 141, 161).

WC of Norwegian children was in the lower range compared with recent data from Europe, although the differences became smaller in older age groups between the northern European countries(138, 145, 179, 180). WC of children from Spain is clearly higher than that of Norwegian children(159). A northern-southern gradient in Europe with higher values in the southern part has also been seen for skinfolds (159, 161), and for overweight prevalence as defined by BMI(7). There could be many reasons for the observed differences, including ethnicity, SES, eating and activity patterns, as well as environmental factors. From the BGS and other studies, it has been shown that as children grow older they act more independently; outdoor activities decline while the intake of fast food, and screen time increase (181, 182). This could explain why differences between countries become smaller in older age groups.

As there is a convincing association between abdominal fat and cardiometabolic risk factors (120, 129), as well as overall mortality in adulthood (124, 125), we believe that at least WC should be routinely measured in the evaluation of an overweight child. It is possible that a combination of moderate overweight combined with a large WC or WHtR should lead to closer follow up than moderate overweight with an average WC or WHtR, but this needs to be further evaluated. It has previously been recommended that skinfolds should be measured as part of a clinical assessment of obese children (165), but this has also been argued against, as skinfold measurements did not seem to give more information than BMI for age in very overweight children (157, 158). In addition, skinfold assessment is unlikely to be used for routine monitoring as the values measured largely depend on the experience of the observer (85). In a primary-care setting the problem of standardization and measurement reliability may be more difficult to control than, for instance, in an obesity clinic or in research studies as the BGS, where a limited number of trained staff members are involved and do the assessments regularly.

Both WC, WHtR and skinfolds may be useful in monitoring trends in fat patterns on a population basis. Earlier studies, including the BGS, have shown that these variables have increased in child populations to a larger extent than the BMI and weight for height (8, 14, 136, 141, 164). BMI monitoring alone may therefore lead to an underestimation of the amount of fat and the corresponding health risk. Consequently, we believe that evaluating trends of WC, WHtR, and skinfolds on a population basis is a valuable and important supplement to BMI trends.

It is important to emphasize that our new references describe the distributions of these variables in our population and do not alone have the potential to describe an optimal or healthy development.

2. Cut-offs

While an increase in final height is a step closer to the genetic potential that is reached under optimal conditions, an further increase in weight-related variables is more likely to mirror an unhealthy development. A very important aspect with weight-related references is therefore how to handle an observed increase. One possibility could be to use an older reference as a standard – under the assumption that the older reference is regarded as optimal. Another approach could be to use different cut-off percentiles to define the unhealthy zone. However, there is still no international consensus on cut-off values for WC, WHtR, or skinfolds.

The usefulness of a cut-off depends on its ability to correctly classify a variable, but also its simplicity in clinical use. With this analysis we wanted to study cut-offs for WC, WHtR, TSF, and SSF in relation to the accepted definition of overweight and obesity, suitable for all childhood ages.

In adults a two-level cut-off for WC, linked with clinically proven risk factors, has been proposed (146). For children there have been reports suggesting the 90th percentile as a cut-off for WC, based on a positive association with multiple cardiometabolic risk factors (131), but as previously mentioned, percentiles of WC, weight, and skinfolds change both with the prevalence of overweight and with ethnicity. This means that limits linked to distribution would have to be reconsidered regularly. In the current study we linked cut-offs for WC, WHtR, and skinfolds with the BMI definition suggested by IOTF (56), and today also the recommended definition for Norwegian health authorities. As mentioned in the introduction, BMI has shortcomings as a gold standard for overweight and obesity, and the BMI cut-offs have a low sensitivity (underestimate excess fat) (183-185), but so far we have no available alternative that has been internationally accepted. Our cut-offs have not been correlated to clinical outcome, which is a weakness, and the limitations in terms of its association with risk factors are the same as for the BMI cut-offs. However, our cut-offs were chosen according to a BMI definition that does not change with an increasing prevalence of overweight and obesity in the population, and therefore correspond to WC, SSF, and TSF values that best describe the current BMI definition of overweight and obesity. A similar approach was used in a study from the Netherlands (138), suggesting 1.3 SDS as a cut-off in screening for increased abdominal fat mass. The proposed cut-offs from this study had high specificities but also very low sensitivities in our population (Table 5), suggesting that common cut-offs may be difficult to define. When comparing the actual values (within sex and age group) for WC, the suggested Norwegian cut-off for obesity (1.6 SDS/95th percentile) was very close to the 1.3 SDS cut-off from the Netherlands.

Future studies with methods offering direct measuring of body fat, and/or linking WC and skinfolds to clinical parameters, can provide WC and skinfold cut-off values independent of BMI. Unless WC assessments become part of the preventive health-care programme, it may be difficult to retrospectively investigate associations between WC in childhood and later mortality and morbidity as has been done for BMI (23). Based on the convincing association between WC and mortality in adulthood (125, 126), and the association between WC and cardiometabolic risk factors in children (131-133), it is reasonable to include a marker of abdominal fat, as WC, into the clinical assessments, and efforts should be done to define clinically based limits for WC, optimally from longitudinal data.

The suggested cut-offs consider the need to avoid misclassification of healthy (not overweight) individuals, in order to avoid unnecessary fear with an incorrect diagnosis, and investigations that are time-consuming, unpleasant, and cost ineffective. This is on some expense of the ability to correctly define overweight individuals (sensitivity). The likelihood ratio (LR) for a positive result was high for both WC and skinfolds, but clearly higher for WC (Table 9).

Skinfolds are due to measurement errors unlikely to be used for routine monitoring in the general population, but may prove more useful in specific conditions where height and weight with the calculation of BMI is more difficult (for instance skeletal dysplasia or cerebral palsy). WC on the other hand may have the potential of being used as a screening variable, either alone or in combination with BMI.

Table 9. Likelihood ratio (LR) for a positive result with suggested cut-offs

Variable	Overweight				Obesity			
	Cut-off	Sens	Spec	LR	Cut-off	Sens	Spec	LR
WC	1.0 SDS	0.79	0.94	13.2	1.6 SDS	0.94	0.96	23.5
SSF	1.0 SDS	0.76	0.92	9.5	1.3 SDS	0.91	0.90	9.1
TSF	1.0 SDS	0.70	0.92	8.8	1.3 SDS	0.86	0.91	9.6

Abbr: LR = sensitivity/(1-specificity); Sens = sensitivity; Spec = specificity

Earlier studies have proposed 0.5 as a unique cut-off for WHtR, associated with increased cardiovascular risks in older children (100). We were not able to define one single cut-off suitable for all age groups, as we could for WC and skinfolds. Above 6 years the 0.5 cut-off showed a high sensitivity and specificity to detect obesity, but below 6 years both sensitivity and specificity were much lower. Different results regarding the 0.5 cut-off have been reported previously (140, 154). There have been some clinical studies that found similar properties for WC and WHtR (0.5 cut-off) in predicting metabolic risk in Caucasian children (148). Although WC would still have to be measured, a 0.5 cut-off would mean that one would avoid the need for age- and sex-specific cut-offs. Based on our findings, particularly the uncertainty in the youngest age group, and the need for an extra measurement, we see no advantages with WHtR compared to WC.

3. Interrelationships between anthropometric variables and overweight during childhood

In Paper 3 we studied the interrelationship between standardized weight-related anthropometric variables used to characterize regional fat and BMI, as a natural continuation of the work described in Papers 1 and 2. The interrelationships between the variables during childhood may shed light on various interesting aspects: The variables may associate differently to BMI in different age groups, and some of these variables may explain more of the variations in BMI than others. In addition to the variables in Papers 1 and 2, we also included SH as well as WSHtR in this study.

The correlations were in general positive and strong. In the extreme ends of BMI the correlations differed little, while in the normal range of BMI the variations were larger. This means that very overweight children consistently have large values for the other weight-related variables, while normal or moderately overweight children showed larger variations in the other anthropometric variables. It has previously been shown that skinfolds improve the prediction of body fatness compared to BMI for age, but not above a certain limit of BMI for age (157, 158). We agree with Freedman et al who suggested that anthropometric variables beyond BMI may be more useful in normal weight to moderate overweight (112). This is also supported by the demonstration that mortality differs between people with the same BMI but different WC, even in the normal BMI range (125, 126).

WC was more closely associated with BMI than any of the variables included. Wells et al found that by increasing BMI/weight, both FM and FFM increased, but FM tended to increase more in the truncal region, while FFM increased equally in the truncal region and the lower extremities (87). WC mirrors this tendency of increased central fat, and according to our correlation studies it seems to do so through all ages and for both sexes. Why different people with the same BMI have different amounts of abdominal fat is likely to depend on individual factors, including genetic factors, as well as the interaction between individual and environmental factors.

Age affected the different interrelationships in a similar pattern: the interrelationships were weakest among the youngest, and strongest between 7–12 years for both sexes and for all variables. We have previously seen a higher prevalence of overweight among 7–11 year-old children in the BGS (7), and it is possible that this could have an impact on the interrelationships. On the other hand this age group has the potential of being a very heterogeneous group as it represents the start of puberty for most girls, while boys are still prepubertal. During these years the amount of fat increases in most girls, while among boys a decrease in fat mass may be seen (63, 109). However, this possible heterogeneity between the sexes does not seem to weaken the interrelationships during these years.

The interrelationships were weakest in the youngest age group. This could mean that weight-related variables in general are more uncertain among the youngest children (below 6 years of age). This is supported in our study of cut-offs (Papers 1 and 2), where the sensitivity was lower among the youngest children. Interestingly, although age affected the absolute value of the correlations, it did not affect the order of variables that most strongly correlated with BMI and best predicted changes in BMI: through all ages and for both sexes, BMI correlated strongest with WC, followed by WHtR, and then SSF. Without being able to conclude on causality, we found it interesting that age differences in the correlations between the weight-related variables match age differences in parental perception, where parents have larger difficulties in recognizing overweight in preschool children.

The ratio between upper and lower body segment is to some extent affected by ethnicity, and some authors have previously raised the question of whether different relative sizes between upper and lower body segments could affect the impact of BMI thresholds on disease risk in adults (186, 187). The ratio between upper and lower body segment changes considerably during childhood. Whether this has any effect on variations in BMI has to our knowledge not been investigated in children before. We could show that SH and WSHtR were more closely correlated with WC than with BMI, and did not predict changes in BMI better than WC or WHtR, independent of age. WSHtR may be a better predictor of abdominal fat than BMI, but it does not seem to be better than WC and WHtR. We therefore cannot see that SH or WSHtR has any advantages or the potential to add information above WC or WHtR.

6.1.2 BMI increments and conditional gain

BMI with cut-offs serve in many countries as guidelines for referral of obese children. The shortcomings of BMI in defining body composition have been debated in many papers (58, 80, 111, 112). Detecting abnormal changes in BMI could be important for preventive purposes – it may be possible even before overweight has established to identify persons at risk by an unexpected change in BMI. Similar strategies have been evaluated for height in relation to short stature (75, 188) and Turner syndrome (76). In Paper 4 we analysed one year BMI increments and calculated conditional change in BMI SDS as an alternative method for evaluating changes in BMI SDS.

Starting with children 6.0 years of age, most of the children have passed the time of adiposity rebound (AR) (16, 189), and as expected we found an increase in median BMI change during our age span, with a peak at the time of puberty. We know from other studies that there are marked changes in body composition between sexes during puberty (63, 99). We could not detect any significant differences in BMI increments between the sexes by this age, indicating that BMI increments as such cannot reveal these changes. This is in accordance with other studies (109, 110).

The regression analysis showed that children with a higher BMI also had larger increments. The largest annual increase we observed in any age group was 2.5 for boys 13 years in the 90th percentile. The difference between the 10th and the 90th percentile did not exceed 2.6 for any age group. The recommendations from the US Expert Committee using an annual increase of 3–4 BMI units, as indicative of a rapid increase in body fat (165), may perhaps be overestimated for Norwegian children, potentially failing to recognize some children at risk (low sensitivity).

Conditional change in BMI SDS offers an alternative way to evaluate changes in BMI between two time points. As far as we know, conditional change in BMI SDS has not been published before. Advantages with this method are that it is not dependent on sex and are the same for light and heavy children, as the conditional corrects for the starting position (Figure 5). The method is limited because it gives no information about body composition, but in most settings outside the obesity clinic there is currently no alternative for anthropometric variables. Our validation study showed a symmetrical distribution but with slightly more children (6%) outside the limits expected from a normal distribution. Covering about 94% of the subjects between -2 SD and +2 SD we still believe that this approach is meaningful and may give unbiased guidance about the change in BMI SDS that is typically observed in the majority of the population. This approach should in the future also be studied using shorter and longer intervals between the measurements, to increase the flexibility of this method. Additional studies are also needed to conclude on the usefulness of the method for the early detection of true overweight, but we believe that it already has a place in a computerized growth journals, to flag children with an aberrant weight development, as supplementary information to BMI.

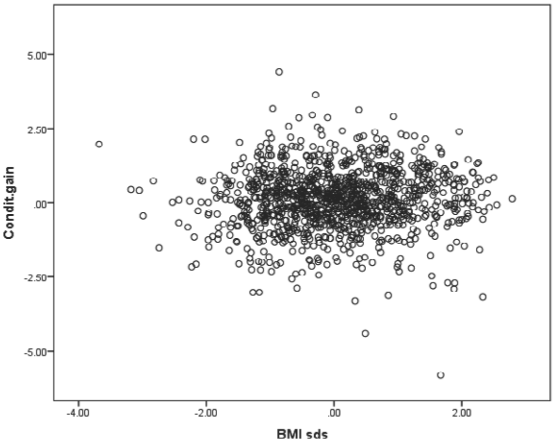

Figure 5. Plot of conditional change in BMI SDS versus initial BMI, demonstrating that conditional change is independent of starting position.

6.2 Methodological issues

Cross-sectional growth studies, like the BGS, are the most practical way to create growth references. As ethnicity and environmental differences influence growth, national references are necessary to deal with variations between populations. Some important questions and limitations connected to growth references and cut-off values will be discussed in the following paragraphs.

Sample size

In medical research it is considered good practice to do a power calculation to estimate an appropriate sample size. This is very rarely done in papers that present growth references, and both the sample sizes as well as age span may differ widely among different studies.

It has been suggested that a survey of 50 cases per year per sex from 0–20 years is reasonable to estimate the mean and SD, but the precision in the tails of the distribution might be poor (190). Sample size was considered by the WHO for the Multicenter Growth Reference study (191). It was emphasized that sample size, as well as age range and the particular measurement are important for the complexity of the shape of each estimated curve in the LMS method. The sample size required depends further on the curve's complexity. From the examples discussed in the literature (191), we believe that a total sample size of 5725 children 4–18 years of age for waist and waist-to-height ratio and 4606 children 4–16 years of age for skinfolds are well within the necessary limits to estimate the curves in the LMS with adequate precision.

Generalizability

The data in the BGS are from one urban area in Norway, the county of Bergen. An important question is therefore whether our sample is adequate for the whole Norwegian child population; or otherwise said: is this truly a national reference? Unfortunately few studies from Norway present WC, WHtR, and skinfold values to which we can compare our data. The NIPH has (section 2.1.1) measured height, weight, and WC in their nationwide survey of children in the third grade. When comparing our data with those, we find a fair agreement for BMI, WC, and WHtR (Table 10).

Table 10. Mean value of BMI, waist circumference (WC), and waist-to-height ratio (WHtR) in the BGS and NIPH							
Study*	**Age**	**BMI**		**WC**		**WHtR**	
		Boys	Girls	Boys	Girls	Boys	Girls
BGS	8 y	16.6	17.0	57.4 cm	56.8 cm	0.43	0.43
	9 y	17.1	17.3	59.6 cm	58.6 cm	0.43	0.43
NIPH	8–9 y	16.6	16.7	58.7 cm	57.9 cm	0.44	0.44

*BGS: Bergen Growth Study, conducted 2003–6 in the county of Bergen. NIPH: Norwegian Institute of Public Health, conducted 2008–12, nationwide.

The NIPH survey found that the prevalence of overweight and obesity, but also WC and WHtR, were higher in small (rural) communities compared with larger (urban) communities (11). As the summary of the NIPH data is quite similar to our data within the same age group, we do not think that including rural areas would affect the reference values substantially, but we cannot totally exclude this possibility for all age groups.

The height and weight in the BGS have previously been compared with the Young-HUNT study (13–19 years) from the county of Nord Trøndelag (rural area) and were found to be quite similar (170). We therefore believe that our sample is a fair representation of the Norwegian child population.

In this study we excluded measurements from children with diseases that could affect growth, which accounted for approximately 1% of the sample. The prevalence of overweight calculated with and without these children did not differ. Therefore it might not have been necessary to exclude these, but it was decided to comply with common practice.

On the other hand we did not exclude children with a non-Scandinavian ethnicity for analysis of weight-related variables. These accounted for approximately 11%. This group was heterogeneous, and the amount of time they lived in Norway, which would probably also affect body composition, was not known to us. We have no indication that the amount of children with a mixed or different ethnicity differ between Bergen and other Norwegian cities, but it is probably higher than in rural areas. However, excluding children with another ethnicity did not affect the prevalence of overweight in our sample.

Errors on anthropometric assessments
Anthropometric measurements are measured externally with a technique and equipment that may look easy to perform at first glance. On the other hand biological aspects of the measured individual (for instance diurnal variation in height) as well as the effort of the observer may contribute to variability and measurement errors that may influence interpretation of the value obtained. Weight and height are among the most precise measurements, while skinfolds have been shown to be more problematic (85). In the BGS, children were measured according to a standard protocol (169), in a restricted time interval during the day, with few observers who were trained both before and during the survey. The equipment was calibrated regularly according to a protocol, and calculated TEM values were in accordance with other studies (57). However, even in well standardized conditions, some errors cannot be totally avoided.

The time aspect
The data in our study were collected between 2003–6. Can we trust that these values are still applicable? A more pertinent question may be whether this is important? A large amount of growth references have been produced using data from previous studies, in some occasions even 20–40 years before. A reference is a description of the distribution at the time of the assessment. The reason for doing regular growth surveys was primarily prompted by the secular increase for height during the past century. This trend has been levelling off in European countries during the last two decades (192, 193). However, while final height has stabilized, weight-related variables like BMI, WC, and skinfolds have continued to increase. As pointed out in section 6.1.1, this is not necessarily an argument for doing frequent surveys to describe the distributions of these variables. An important aspect of presenting new references for WC, WHtR, SSF, and TSF in our study was to provide tools, in addition to BMI, to monitor overweight in children, and also to create a platform for further studies: on cut-offs in relation to overweight, on secular trends in weight-related variables associated with regional fat, and on the associations between these variables and health outcome. However, when we compare our data from 2003–6 with those from NIPH (2008–12), we have no reason to believe that weight, height, BMI, WC, or WHtR have changed much

during this period, but this is a very restricted age group, and no information on skinfolds was available for this period.

Cut-offs

Diagnostic criteria, limits, and cut-off values are terms frequently used in the clinic, but they rarely constitute a true and absolute threshold. Anthropometric variables are of course represented as a continuum in a population, and cut-offs may be more or less arbitrary. Both in preventive and clinical settings, it is important to define the purpose of the limits, as the value of the cut-off may change according to the use and the need to avoid misclassification. The cut-offs suggested in this study highlight the values that describe BMI-based overweight and obesity with minimal risk of positive misclassification, but care should be taken with the interpretation of these limits, as they are not clinically validated. A weakness in our study is the lack of more specific information on body composition that could be provided by investigation with DXA, BIA, or MRI. On the other hand it is unlikely that for instance DXA studies would be large enough to provide growth references. Our study is therefore a first step, and a follow up study could include validation of the references and further refinement of the cut-offs.

7.0 Conclusions

This study has focused on weight-related anthropometric variables in childhood, in the context of an increasing prevalence of overweight among children. Considering the results of the study, as well as the methodological limitations, we draw the following conclusion in relation to the aims of this study:

1. Weight-related anthropometric traits beyond BMI

- By creating growth models for WC, WHtR, SSF, and TSF, we were able to calculate and present the distributions of these variables in a representative sample of healthy Norwegian children. WC and skinfolds increased with age as part of the normal growth and maturation of a child, but the high rate of linear growth before puberty resulted in a decrease in WHtR. We found evidence of a sexual dimorphism comparable to findings in other countries, with a higher WC in boys than in girls at almost all ages, and similarly a larger skinfold thickness and hence, more subcutaneous fat in girls than in boys. The WC of Norwegian children was in the lower range compared with other recently published references from the northern part of Europe, a trend that is comparable with the prevalence of overweight and obesity as defined by BMI.
  We are now able to include markers of regional fat in the evaluation of Norwegian children as an addition to the BMI evaluation, or as a single evaluation where BMI may be difficult to obtain. The distributions of WC, WHtR, SSF and TSF do also provide a platform for further studies on regional fat patterns and health risks, as well as for monitoring trends in the future.

- Cut-off values in relation to the IOTF's BMI criteria for overweight and obesity, that are suitable through the studied age span and for the present population, could be calculated for WC and both skinfolds. For WHtR we could not define a single cut-off, as the optimal limit differed largely by age. Because there is no international consensus about cut-offs for these variables, the cut-offs presented here provide guidance on which values that best match the current definition of overweight and obesity with minimal risk of false positives.

- The interrelationships between weight-related anthropometric variables during different ages showed that WC was the variable most closely associated with BMI and BMI variations during all ages and for both sexes. The interrelationships were strongest between 7-12 years and weakest below 6 years of age. It is possible that weight-related anthropometric variables are more uncertain among the youngest children, compared to older children. This is also supported by a lower sensitivity for the cut-offs below 6 years of age.

2. BMI increments and conditional gain

- BMI increments increased slightly with minor variations until 13 years of age, but with no significant differences between the sexes. This supports previous findings that BMI increments do not reveal known differences in body composition between sexes at puberty. Children with a higher BMI had in general higher increments. Conditional change in BMI SDS is an unbiased method to evaluate the change in BMI compared to the population mean. The method showed a symmetrical distribution that covered about 94% of the children between + 2 and - 2 SD. Whether this method is useful as a guide for early detection of overweight risk needs to be further studied, but we believe that it is useful, implemented in a computerized growth journal, to flag children with an aberrant weight development, and used as a supplement to BMI.

8.0 Future perspectives

The new references for WC, WHtR, TSF, and SSF, and conditional change in BMI SDS provide clinical, scientific, and epidemiological opportunities for the future:

From a clinical point of view, the link between abdominal fat and various components of cardiometabolic risk in children, including factors connected with the metabolic syndrome, is convincing. The International Diabetes Federation has stated that abdominal obesity should be measured as part of the diagnostic approach to metabolic syndrome in childhood (194). Body fat reference curves with both regional and segmental body composition are valuable tools in the evaluation of overweight, fat patterns, and health risks. These are, however, based upon technology that is not available outside laboratories and a very few clinics. This technology will most certainly become available in obesity clinics in the future, but it is also likely that anthropometry will remain the choice for preventive health care and general practice for many years to come. We therefore find it reasonable to implement measurements of WC as part of routine assessment in the evaluation of overweight children as a supplement to the BMI. Skinfold evaluation should be regarded as an alternative method for measuring fat where BMI may be difficult to obtain. Further, with conditional change in BMI SDS with the integration of a 'red-light signal' —children at risk could be identified even before overweight has established, which provides opportunities for early intervention and prevention of overweight. Further studies on conditional change, using different time intervals between the measurements to increase the flexibility and to define optimal intervals, should be done, and the usefulness should be evaluated.

Results from further studies will give the necessary scientific base to implement new routines regarding the assessment of children in the future. In Norway very few studies have examined the association between health risk and weight-related variables in childhood. With our references, further studies on the connection between regional fat pattern, health risk, and lifestyle are possible. A study on lifestyle factors associated with WC, WHtR, and skinfolds is ongoing, and the skinfold references have already been used in a study of Norwegian children with cerebral palsy (115). Through clinical studies it may be possible to define national clinically based cut-offs in the future, and to test the suggested cut-offs against clinical outcomes. It is possible that weight-related variables beyond BMI may have a greater potency in distinguishing fat patterns and thus health risks in children with a normal weight or moderate overweight than in children with extreme overweight, but further studies are needed to confirm this.

From an epidemiological point of view, our new references will be useful to monitor secular trends of regional fat patterns in the future. Instead of planning expensive and time-consuming regular surveys with a restricted (and possibly biased) population, another possibility in the future would be to collect all measurements from children in well-baby centres and from schools in a national register. In Norway, all these measurements are already computerized, but unfortunately only in regional systems. A common national register would be a very important resource for health authorities and scientists in the future to monitor secular trends, and for the follow up of the current obesity epidemic among children.

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10.0 Errata

The corrected text is written in italic.

Paper 1, page 4, column 1, line 15. Correct text should read: ‘The previously recommended cut-off value of 0.5 has a high *specificity* (97%) and *sensitivity* (87%) to detect obesity in 6–18 year-old children, but a much lower specificity (90%) and sensitivity (63%) in children under 6 years.

11.0 Epilogue

Performing a quick advanced google scholar search covering 2014 and 2015 (May 2015, around 7500 results), reveals that the debate concerning overweight and overweight diagnostics in children does not show any signs of fatigue. The key questions in clinical epidemiology and in the clinic; *what is normal/abnormal*? - and *what is healthy/not healthy*? - are essential to support decision making both for preventive as well as for clinical issues. With regard to childhood overweight these questions are not less important and engage colleagues around the world. There is reason to believe that this is all part of a long lasting story. In the mean time we continue to measure what is measureable, and make measurable what is not so.