Growth of schoolchildren
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Studies of somatic growth and deviant growth patterns such as weight loss and obesity and aspects of intake of breakfast and food items
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Abstract

The overall aim of this thesis is to explore somatic growth, and deviant growth patterns as episodes of weight loss and obesity development, including some aspects of meal patterns and food intake.

**Methods:** The thesis includes four studies, two cross-sectional studies (Paper I and II), and two longitudinal studies (Paper III and IV).

The first paper looks at assessment of BMI categories (underweight, overweight and obesity) prevalence and how the results relate to which growth reference that is used. Height and weight measurements of 4,518 Swedish schoolchildren aged 7–9 years were collected in 2008 using a standardised protocol from World Health Organization (WHO). Four growth references were used, from the WHO, the International Obesity Task Force (IOTF) and two Swedish growth references from Werner and Karlberg et al. (Paper I). Parts of the same data set plus a follow-up data set from 2010 was used to investigate correlations with deviations in BMI in relation to breakfast habits and selected food frequencies.

For paper three and four, a longitudinal material from two nationally representative samples was used with height and weight data of 6,572 schoolchildren, born 1973 and 1981. Episodes of BMI reduction of 10% or more were identified and correlated to final height (Paper III). The same material was used for paper four to further investigate growth patterns on group level by use of weight for height, Tri-Ponderal Mass Index (TMI), apart from BMI. On individual level, weight at age 7 years and weight at 16 years for girls and 18 years for boys, were categorized in monthly values and expressed in standard deviation (from ≤ -2 to ≥ +3 SD) (Paper IV).

**Results:** Depending on which growth reference we used, the prevalence of different degrees of thinness varied greatly. There were also significant gender differences depending on the growth reference we used (Paper I).

The majority of parents reported that their children (95.4%) had breakfast every day. The odds of being OW/OB was higher among those not having breakfast every day (odds ratio (OR) 1.9, drinking diet soft drinks OR 2.6, 95% and skimmed/semi-skimmed milk OR 1.8), four days a week or more (Paper II).

There was no statistically significant difference on group level in final height between individuals with and individuals without BMI reduction, independent of age and if the individuals were thin, normal weight, overweight or obese at the start of the BMI reduction episode (Paper III).

Almost the same longitudinal growth patterns were found for the two cohorts, even if weight and BMI for all almost all ages were higher in 1981 cohort. Patterns for TMI differs from those of W/H and BMI. Three main longitudinal trajectories represent the description of weight development from 7–16 years for girls and 7–18 years for boys. These patterns were mainly the same in the 1981 cohort and the 1973 cohort. (Paper IV).

**Keywords:** growth, body mass index, overweight, weight loss, body weight, malnutrition, breakfast intake, food habits, schoolchildren

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List of publications


Paper IV  Nilsen, B. B. & Werner, B. The longitudinal development of body weight among individuals from age 7 to 18 years in Sweden (in manuscript)

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Abbreviations, concepts and glossary

*Adolescents growth spurt*—the rapid and intense increase in the rate of growth in height and weight that occurs during the adolescent stage of the human cycle

*A meal*—can be defined as food eaten as part of a structured event

*Anthropometry*—the science of measuring the human body (height, weight and proportions)

*Anorexia nervosa*—a disorder in eating behaviour characterised by a pathological fear of gaining weight and by low body weight, and an inaccurate perception of body weight or shape

*Anthropometric measures*—body measures, for example height, weight, and relative weight

*Auxology*—the science of physical and physiological growth of man (auxein=to grow, to increase)

*Benn index*—an index that in a statistical sense is highly correlated with weight and uncorrelated with height. Benn index is generally formulated weight/height^n, weight divided by height^n, where n is a number calculated from the data to ensure zero correlation between the index and height

*Binge eating*—a condition featuring episodic uncontrolled consumption, without compensatory activities, such as vomiting or laxative abuse, to avert weight gain

*Body mass index, BMI*—weight (kg) divided by the square of height (kg/m^2). Higher BMI scores indicate that an individual has relatively more weight-for-height than a person with lower score. In the general population, higher BMI scores usually indicate more body-fat

*Bulimia nervosa*—an eating disorder characterised by compulsive over-eating usually followed by self-induced vomiting or laxative or diuretic use. This also include binge eating, and compensatory activities

*CAMS*—Culinary Arts and Meal Science
**Catch up growth**– can be defined as a height velocity above the statistical limits of normality for age and/or maturity during a defined period of time, following a transient period of growth inhibition (recovery from disease or re-feeding after short-term starvation), or no or minimal increases height velocity but the duration of growth continues longer.

**Childhood phase**– a stage in the human life cycle that occurs between the end of infancy and the start of the juvenile phase

**Cross-sectional study**– measurement from a single occasion of individuals grouped by age, sex, and sometimes other characteristics

**Dedicated study**– a study performed that is especially arranged with a controlled situation when measuring according to method and age

**Descriptive**– how growth is at a defined point of time or period

**Dietary records**– records of the intake of food and drinks over one or more days

**Distance curve**– a graphic representation of the amount of growth achieved by an individual over time

**Diurnal variation of standing height**– the variation that signifies that an individual is tallest in the morning after sleep and shortest at the end of the day before sleep

**Early maturer**– an individual with early puberty and maturing

**Eating disorders**– includes anorexia nervosa, bulimia nervosa, binge eating or ENDOS.

**ENDOS**– eating disorders, which are not otherwise specified

**Epidemiology**– the study of the distribution and determinants for disease frequency

**Epigenetics**– can be defined as the study of heritable changes in gene function that do not involve changes in the deoxyribonucleic acid (DNA) sequence
**Failure to thrive**– a state of undernutrition due to inadequate caloric intake, inadequate caloric absorption, or excessive caloric expenditure with no previously known disease explaining the condition

**Final height**– when no more height can be achieved

**Foetus**– stage of prenatal development lasting from the tenth week following conception to birth

**FFQ**– food frequency questionnaires

**Growth**– refers to the increase in the size of the body as a whole and of its parts.

**Growth chart**– is a growth reference presented in a visual display for clinical use which display both the size of a child at various ages and their growth rate and velocity over time, based on the slope of the curve

**Growth phase**– a part of growth of an individual that can be defined specifically

**Growth reference**– is a statistical summary of anthropometric measurements of different individuals at different ages

**Growth standard**– is essentially the same as a growth reference except for the underlying reference data is selected on health ground, where such a prescriptive approach aims to describe how children should grow rather than how they grow.

**High birthweight**– a birthweight of 4500 g or more for a neonate of normal gestation length

**Infant phase or infancy**– a stage in the life cycle. For human beings it lasts from the second month after birth to the end of lactation, usually by the age of 36 months

**Large for gestational age (LGA)**– see high birthweight

**Late maturers**– individuals that have late puberty and maturing. One of the consequences of this is, for example, for boys sometimes growth is up to the age of 25 years
Longitudinal study– measurements of the same individual or group of individuals, repeated over time

Low birthweight– a birthweight of 2500 g or less for a neonate of normal gestation length (SGA)

Mean– is the sum of the observation divided by the number of observations

Median value– the value that divides a distribution of data in two similar big parts. It is the same as P50

Medical Birth Registry, MBR– a registry that includes birth data for all newborns in Sweden since 1973

Menarche– the first menstrual period

Migration– the movement of people from place to place

Military Service Conscript Registry, MSCR– a registry that includes, among other things, growth data collected at military conscription in Sweden

Nutrition– the process where living organisms take in and transform extraneous solid and liquid substances necessary for maintains of life, growth and the normal functioning of organisms and the production of energy

Tri- Ponderal Mass Index, TMI– weight divided by the cube of height (kg/m³).

Prescriptive– how it (growth) ought to be

Prevalence– the total number of all individuals who have an attribute or disease at a particular time (or during a particular period) divided by the population at risk of having that attribute or disease at this point in time or midway through the period

Puberty– is the process of physical changes through which a child’s body matures into an adult body capable of sexual reproduction. Puberty occurs at the end of the juvenile stage and is the period that starts with PHV and where menarche of girls put a relative upper limit for further growth.
Usually a girl grows only 6–8 cm after menarche, seldom more than 10 cm and just in an extreme case, grows by 12 cm

**Reference values** – constructed values as reference to compare individuals with

**Relative weight** – see further: body mass index (BMI, kg/m²), tri-ponderal mass index (TMI, kg/m³), Quetelet index (k/m²), Benn index (kg/mⁿ)

**Standard deviation, SD** – a measure of distribution

**Secular change** – (secular trend) – the process that results in a change in the mean size or shape of individuals of a population from one generation to the next

**Sexual dimorphism** – different characteristic between boys and girls beyond their differences in their sexual organs

**Skewness** – a statistical measure that gives information on the deviation from normality, within each interval. It should be close to zero in the case of an approximately normal distribution within the interval

**Small for gestational age (SGA)** – see low birth weight

**Socio-economic status, SES** – an indicator, often defined by measures of occupation and education of the parents or head of the household, used as a proxy for the general quality of the environment for growth and development of an individual

**Standard values** – (growth standard) – normative values for growth

**Stunting** – low height for age

**The 24 hour recall method** – a record of the intake of food and drinks from the previous day

**Thinness** – low BMI for age, according to the growth reference from IOTF < 18.5 kg/m²

**Underweight** – low weight for age, according to growth reference from WHO < -2SD

**Quetelet index** – see body mass index (BMI).
**Z-scores** is the number of standard deviations (SD) from the mean a data point is, or put another way, a measure of how many SD below or above the population mean a raw score is.
1 Introduction

The postnatal growth from birth to adolescents is the result of a continuous interaction between genetic and environment (1). In Western countries about 80% of the variation of body height is genetic, and about 20% is due to environmental factors. To what degree the genetic potential is realised depends on several environmental factors (2).

As a result of improved living conditions and changes in lifestyle in most affluent countries, there is an ongoing positive secular trend for growth where the mean height and weight have increased in the last centuries (1-3).

Since the 1960s, the prevalence of overweight and obesity among the adult population has increased, simultaneously an increase in overweight and obesity among children and adolescents has been developing during the last forty years (3).

Overweight and obesity in childhood predicts a substantial part of obesity in adulthood, potentially causing health consequences and premature death (4). Parallel with the overweight and obesity development, there are subgroups of children and adolescents within the population that experience different degrees of weight loss episodes (5).

Irregular meal patterns, large portion size, low intake of fruit and vegetables, high intake of foods rich in fat and sugar, regular intake of sugar containing soft drinks may all play a part in the development of overweight and obesity among children. The importance of healthy food habits and food intake for a healthy weight development cannot be overemphasised (4,6-12), this is also with regards to underweight and thinness (2,13).

This thesis is a part of research in the interdisciplinary field of Culinary Arts and Meal Science (CAMS) (14), which includes three integrated areas: the meal for health, safety and sustainability, the meal in the society and the meal experience with an aesthetic perspective (15). The research in the field CAMS and especially research on meals encompass a multitude of topics (16,17).

In order to deal with the complexity of research on meals and subjects related to meals, a multi and inter-disciplinary approach is applied and several methodological perspectives are used, from natural science, social science and humanities (18).

The importance of the nutritional part of meal science is recognised by Gustafsson (2004, p. 13-14),
“The ties between the ‘food & health’ sphere, medical research and nutrition are obviously strong ones and are important when it comes to the prevention of the increasing body weight and the incidence of diabetes mellitus in our society. Here, the restaurants and CAMS researchers should cooperate with physicians and dieticians to create healthier restaurant menus” (17).

Previous research in the fields on CAMS has been in the fields of sensory science (19,20), the cultural aspect of the meal (21-23), customer experience (24,25), organisation and professionalism (26). Only one previous research project has focused on meals and health (27). In the field of CAMS, this thesis also focuses on health, explores somatic growth, and is to be considered as a contribution to meal science in order to strengthen the knowledge of how children grow and the factors influencing growth. It describes the situation with regards to malnutrition in the population from the point of view of growth development, which is a powerful indicator of population health. The public meal industry, retail, parents and the educational system jointly carry a responsibility with regards to providing knowledge and products for a healthy childhood development. This thesis can provide background knowledge regarding the trends in childhood growth in Sweden to those responsible for the health of children in private and public domains and also emphasises the importance of healthy meal provisions in day care centres, schools and restaurants as well as in the family setting.

1.1 Human Growth

This thesis explores somatic growth, and deviant growth patterns as weight loss and obesity, with some aspects of meal patterns and food intake.

1.1.1 Auxiology

The field of auxiology, the study of human growth, goes back to the seventeenth and eighteenth centuries, where attempts at studying human growth started. The early studies were often case studies, later on, in the twentieth century, the larger and more systematic population data surveys, dependent on governmental involvement and support, were conducted (28).

Some of the milestones in auxiology worth mentioning are: the first longitudinal study by Montbeillard from 1759 to 1777, where heights of his son were measured every six months from birth to adulthood. These height measurements plotted on a curve, illustrated the rate of growth/year (29). The first study of height among British factory children by Chadwick in 1833 found that children working in factories were stunted (low height/age). As a result of these findings, the Factory Regulation Act of 1833
was passed, which among other restrictions, prohibited children under 9 years to work in some types of textile factories (30).

In 1832 Quetelet, under the premise that the transverse growth of man is less than the vertical, derived the function of characterised relative body weight as the ratio of weight (kg) over height (m) squared, the Quetelet index (31), which in 1972 was renamed the Body Mass Index (32). In a longitudinal school survey of height among U.S. children by Bowditch in 1877, gender differences in growth were established (28). By the twentieth century important progresses in auxiology were made. Growth studies by Boas in 1891–1932 identified the relationship between the tempo of growth, the concept of developments age and the height distribution. Later, Boas developed national standards for height and weight. The first large longitudinal study on children’s growth in the U.S. was supervised by Baldwin in 1914 (28), and finally, models underlying clinical standards were developed by Tanner in 1952 (33).

1.1.2 From conception to adulthood.
Human growth and development are defined and characterised by the way changes in shape, size, and maturity, which occur relative to the passage of time among humans (34). From the very beginning when fertilization takes place, the cell divides and grows, and through differentiation, it develops into the embryo, foetus, infant, child, adolescent and adult (29).

Growth for body height and weight may be defined as a quantitative increase in size or mass, with the endpoint of growth for height when the individual reaches final height (34,35). Measurements of height in centimetres or weight in kilograms indicate how much a child has grown (36).

Development is the increase in functional ability, and can be defined as the progression of changes among individuals from an undifferentiated and immature state to a highly organised specialised and mature state (35), and entails biological, emotional and physiological changes from dependency to autonomy. The endpoint for maturity is when the individual is functionally able to reproduce successfully, which in a biological sense, requires that the offspring survives so they themselves are able to reproduce. In addition, a successful maturation also requires a degree of behavioural and social maturity (34).

The relationship between somatic growth and maturity is not always obvious. In extremely general terms, someone who is tall is more likely to be older and more mature than someone who is small, however, there are large differences between individuals. This can be illustrated by the adolescent
phase where the adolescent growth spurt take place. The growth spurt will start and finish as a result of hormonal changes that occur during sexual maturation. The timing, duration and magnitude of the growth spurt and the maturation can vary greatly among individuals within the same population (37), where boys or girls at the same chronological age may demonstrate vastly different degrees of maturity (34).

1.1.3 Growth as a mirror of conditions in society
During the last centuries, individuals in most developed countries are growing taller (1). In order to understand this development, it is necessary to take into consideration the onset of modern economic processes and their effect on biological well-being (38). Factors such as economy, health care, infections, nutrition and water supply have influenced human growth (2,13), where the two most important non-genetic factors affecting growth and adult body height are nutrition and infections in childhood (39).

1.1.4 Nature and nurture
It is obvious that the ultimate size and shape of an individual attains, is the result of a continuous interaction between genetic and environmental influence during the whole period of growth (1). The individual’s biological potential for growth is passed through the DNA from parents to the child (29), where the genotype determines the potentialities of an organism (40). Human growth is a polygenic process, where several genes in an intricate interplay regulate human growth (39,41,42). In the medical literature several conditions of chromosome deficiency or gene mutations are described, which influence growth and causes short stature (43-45). However, in recent year new knowledge in the field of epigenetics is about to change how we understand genes and their function (46). Epigenetics can be defined as the study of heritable changes in gene function that do not involve changes in the deoxyribonucleic acid (DNA) sequence. Epigenetic changes occurs naturally, but are also influenced by several factors such as environmental, lifestyle, age and disease (47).

In a literature review, Silventoinen (39) concluded that in Western countries about 80% of the variation of body height is genetic, and about 20% is due to the environmental factors. Even if genes play a considerable role in human growth, to what degree this genetic potential is realised depends on several environmental factors (2). A considerable proportion of the mean difference in body size between the respective populations and also on the
individual level within populations is due to effects of different environmental factors. A healthy and well-nourished population is a tall population while a poor and undernourished population is shorter \((29,40,48)\).

A child requires an adequate intake of nutrients and energy to maintain its body mass, to undertake physical activities and to grow. The child must also combat infections or other diseases, or different forms of stress such as emotion deprivation \((40)\). If the normal balance between nutrients supply and the demands of nutrient is compromised, child growth will slow down \((29)\). Weight is first effected, and if the situation of scarce nutrition intake persists, height will also be affected \((40)\). When the nutrition situation is restored, weight and height growth will return, and for a period the child will grow faster than before, which is the so called “catch-up” growth \((40,49)\).

1.1.5 Factors that influence growth
Several studies have investigated the relationship between socioeconomic factors such as social class \((2)\) and its influence on the child’s growth pattern and final height \((50)\). Children from families belonging to high or middle socioeconomic groups in nearly all countries are taller than children from lower socioeconomic groups \((1,2,51)\). Among such factors that influence human growth are income and education \((52)\), family size and area of living such as urban or rural \((53)\).

Steckel (1995) illustrated how socioeconomic determinants are to be understood as a complex web of factors in an interplay with each other such as income, inequality, public health, diseases, technology, access to food and food prices, culture, occupations and migration \((28)\).

A study of socio-demographic determinants for height among Finnish adults show that height was strongly associated with childhood living conditions, and the education level attained among adult men and women. Further on, short stature was associated with poorer health among both men and women \((54)\). Correlation between stature and health was also described by Waaler \((55)\), where an increase of mortality due to cardiovascular diseases was found among individuals with short stature. Additionally, for overweight and obesity among children and adolescents, several studies suggest an association between low socio-economic status and higher prevalence of overweight individuals than for those from higher socio-economic groups \((4,56)\).
1.2 Growth from foetus into man

1.2.1 Secular change of height and weight
Since the 19th century a clearly positive secular change for height and weight has been documented in most European countries among adults (57), the same positive secular change is also observed among infants, children and adolescents. These trends arise from two distinct sources, increase in body size (height) and changes in body shape which correspond to adiposity (3). There are also periods with a decrease in height which typically occur during wartime or crisis (1). During the Nazi-occupation of Norway (1940-45), there was a drop in mean height of 1.5 cm among 8–14-year-old individuals, followed by a rapid catch up growth after 1945 (58).

1.2.2 Growth phases
Even if human growth from birth to final height is a fairly regular process, it is not a linear process, an individual does not gain the same amount of height during each calendar year. In regards to tempo, growth is rather something that occurs in phases (29,59). Bogin (35) described four phases for growth, the infant phase from birth to about 3 years, the childhood phase from about 3 years to about 7 years with fairly stable growth, the juvenile phase from about age 7 to about 11 years and the adolescent phase from about 11 to 18 years with rapid growth. Walker & Walker (60), divided growth into six phases: the neonatal phase, the infantile phase, the early childhood phase, the mid childhood phase, the late childhood phase and finally the pubertal phase.

1.2.3 The foetus
The health and nutrient status of a woman before and during pregnancy is important for a healthy pregnancy (61). Characteristics of the mother such as underweight, short stature, mother herself being small at birth (SGA, small for gestational age), and poor gestational nutrition will compromise a healthy pregnancy (62). A rather well known description of the “Dutch Hunger Winter” during Second World War showed an association between early fetal undernutrition and later obesity and coronary heart disease among the offspring (63,64).

Placenta abnormalities (65), diseases in the mother such as renal or cardiac diseases are some of the risk factors for the child born being small (SGA, small for gestational age) (66-71). Among infants of diabetic mothers
there may be an foetal over-nutrition that increases the risk of glucose in-
tolerance later in life (72). Maternal obesity is associated with an increased
risk of giving birth to large infants (LGS, large, for-gestational age), and
obese mothers have an increased risk of diabetes. Obese mothers also have
a higher risk for hypertensive disorders including preeclampsia, which
might results in preterm delivery and low birthweight infants (73).

1.2.4 Birthweight
Birthweight is as a public health measure where the child’s birthweight is a
result of the mother’s health and the intrauterine conditions of the foetus
(74). At birth, the difference in length and weight are present between the
genders, in general the boys are slightly longer and heavier than the girls
(75).

In Norway, the mean birthweight increased from 1967 to 1998 by 100
grams among infants born in week 40 (76), and in Denmark, from 1973 to
2003, the mean birthweight increased by approximately 160 grams, an av-
erage yearly increase about 5 grams (77). According to the Swedish Medical
Birth register the mean birthweight among firstborns and total in Sweden
from 1973 to 2015 has remained fairly stable (Table 1) (78).

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<tr>
<td>High birth weight, &gt;4500 g**</td>
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<td>2.8%</td>
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<td>3.1%</td>
<td>3.9%</td>
<td>4.1%</td>
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*Mean birthweight in grams. **Percentage based on birthweight, total.

Table 1. Development in mean birth weight from 1973 to 2015 (78).

Additionally, over a thirty years period (from 1973-2004), the infants
with a birth weight of more than 5000g have doubled in Sweden (79), the
same increase of infants birth weight of ≥ 4000g was observed in Denmark
in a period of nine years from 1973–2003 (77,80), and in other countries
(81,82).

However, there are some methodological challenges with some of the
studies, for example they do not report on multiparity (77,80), differences
between genders (77,80) and the prevalence of children born small for ges-
tational age (SGA) (80), all factors which may influence birth weight in a
population. The reported increase in birthweight is explained by factors
such as lower number of mothers smoking during pregnancy, increased maternal weight (including overweight and obesity) (81,83), multiple parity (81) and a better antenatal, obstetrical and neonatal care during the last decades (84).

An increase in birthweight may be considered as an indicator of a healthy society with a high standard of living, on the other hand giving birth to large infants of 4000g or more is also a potential risk for the mother such as rupture and additional bleeding and other complications during and after delivery (85). Another concern is that a high birthweight has been associated with overweight or obesity and diabetes later on in life (86-88), or indeed increased risks of certain childhood cancers (89,90). Additionally, among small-for-gestational-age (SGA) infants there is a reported increased risk for overweight because of the fast postnatal weight gain, indicating that early growth pattern or catch-up growth are predictive of childhood and later, obesity and coronary heart diseases as adults (70,71,91-94).

1.2.5 Infancy
Infancy is a high-velocity, nutrition dependent phase of growth. During the first year of life, the infant grow extremely quickly. From birth to about 6 months the infant grows about 30 cm per year and from about 6 months to about 1 year about 25 cm per year. Besides growing in size, the child experiences profound developmental changes in the central nervous system, which provides the basis for further psychomotor and intellectual development. The infancy is called the nutrition dependent phase of growth because nutrition is the main factor influencing growth (59).

An infant’s birth weight is strongly related to prenatal growth which is an expression of the fetus’s intrauterine conditions and the size of the mother (height and pelvic size). The newborn does not express the size genetically determined by the parents. It is during the two first years of life that the child’s genes linked to the growth passed down by the parents, becomes activated and it is around 2-years-of-age that the child achieves its their genetically determined location in the percentiles (34). Smith et al. reported that about two-thirds of healthy children shifted percentiles upwards or downwards during the first two years of life (95).

1.2.6 Childhood
Childhood can be divided into early childhood from about 3–8 years and middle childhood from 9–11 years. The childhood phase is described as a
period with fairly stable growth (34,36), with a small growth spurt between the ages about 6–8 years (59).

Most body measurements follow approximately the growth curves described for height. The majority of skeletal and muscular dimension, and also intestinal organs such as liver, kidneys, spleen (29) and lungs (96) grow in this manner. However, some exceptions exist. The “growth curve” for the brain have a steep rise during the first years of life, achieving almost 85% of its adult size at the ages of 2–3 years (59), heart volume and mass follow the growth pattern similar to that of body weight (96). Growth of body fat also follows a different pattern than that for height. The baby is born with a rather small amount of fat and during the first year, the fat tissue increases substantially. After the first year of life the skinfold curve decreases in the next 4–5 years, where the baby changes from its initial plump, baby like appearance into a leaner, slender body build coincidentally with the period where the child show important development in motor skills. In school years, skinfold and percentage of body fat as for height velocity, remain fairly stable (59).

1.2.7 Adolescence
The adolescent period is the transition from childhood to adulthood. The adolescence is considered to start with the onset of puberty with its appearance of secondary sexual characteristics and the start of the adolescent growth-spurt. At the end of this period, most individuals have reached their final height. The age of onset of the puberty growth spurt varies considerably among populations and between individuals within populations. Generally, the maximum velocity for height (or peak height velocity, PHV) is about 3–3.5 years after the onset of the growth spurt. After reaching the peak, the growth velocity decreases rapidly and ends at full maturity at about 16–17 years among most girls and 18–19 years for most boys in the western populations (37).

1.2.8 18-year-old men
A way of getting an idea of the secular changes in body height is to compare repeated measurements of samples representative for the population in question. Example of this is cross-sectional data of height among conscripts. As a part of the medical examination in preparation for military service, almost complete populations of young men in most European countries were measured for height. This provided good data collections for the esti-
mation of height for a population, and this changes over time (40). Norwegian recruits’ records exist from 1741, in England from 1755 and for Swedish recruits from 1767 (13).

When comparing the mean height for conscripts, in some countries almost whole populations were measured at a particular age, in other countries only those young men selected for military services were measured and in cases of voluntary-armies the height many not be representative for the population as a whole (97).

In Sweden, in about 100 years of conscript data for height from 21-year-old men in 1841-45 , (born from 1820–24) to 19-year-old men in 1952 (born in 1933), mean height increased with 8.4 cm from 167.4 cm to 175.8 cm (79). The ongoing positive secular trend was also identified among 18 years old conscripts (born in 1944 to 1988), from 1962 to 2004, where the mean height increased with 2.8 cm, mean weight 8.9 kg and mean BMI with 2.1 kg/m² (Table 2).

![Table 2. Height, weight and BMI development for 18-year-old Swedish conscription from 1962–2004 (born 1944–1986) (98)](image)

<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (m)*</td>
<td>177.4</td>
<td>177.7</td>
<td>178.7</td>
<td>179.0</td>
<td>179.1</td>
<td>179.2</td>
<td>179.4</td>
<td>179.8</td>
<td>180.2</td>
</tr>
<tr>
<td>Weight (kg)*</td>
<td>65.8</td>
<td>66.0</td>
<td>68.0</td>
<td>69.0</td>
<td>69.6</td>
<td>70.2</td>
<td>71.5</td>
<td>72.8</td>
<td>74.7</td>
</tr>
<tr>
<td>BMI (kg/m²)*</td>
<td>20.9</td>
<td>20.9</td>
<td>21.3</td>
<td>21.5</td>
<td>21.7</td>
<td>21.9</td>
<td>22.2</td>
<td>22.5</td>
<td>23.0</td>
</tr>
</tbody>
</table>

*Mean value for height, weight and BMI

1.2.9 Final Height

At what age we reach final height has varied through time. As described in previous chapter, final height among Swedish men has increase during the last 100 years. As illustrated in Table 2, final height among 18-year-old Swedish conscripts increased with 2.8 cm from 1962 to 2004. However, Werner showed a decelerating mean height incidence over time. For 18-year-old men in Sweden from 1953 to 1962 mean height increased with 1.7 cm, from 1962 to 2004 with 2.8 cm and from 1994 to 2004 with only 0.7 cm. The explanation could be that final height is reached at an earlier age (79).

Data from the repeated national surveys from the Netherlands show that the growing population is extremely tall in all age groups and for both gen-
ders. Between 1955–1997 the mean height in the Dutch population was increasing (99). However, in 2013, Schönbeck et al. reported that mean height among Dutch children in 2009 was about the same as in 1997 and concluded that the 150 year secular positive trend for height has come to an end, at least temporarily. There are no obvious reasons for the observed halt in height development, though Schönbeck et al. hypothesised that the mean height of the population has reached the maximum possible. It could be that within the Netherlands, the best achievable at country level is a mean population height of 184 cm for boys and 171 cm for girls. Other plausible explanation pointed out by Schönbeck et al., could be environmental factors such as unhealthy eating habits, sedentary lifestyle, increased overweight and obesity all which may lead to impaired height development (100). In the Dutch sample the first and second generations of immigrants from outside Western countries are excluded, in addition to a substantial number of missing cases especially among older teenagers (100), which could make comparison with other national data hard to evaluate. Still it would be interesting to see if this phenomenon is present in other populations.

1.2.10 Gender differences

Sexual dimorphism, or different characteristic between boys and girls beyond their differences in their sexual organs. In humans, the sex differences in body composition are visible from birth (101), and even if the fat mass is about the same for boys and girls at birth, the boys are slightly heavier and longer than the girls (102). The sexual dimorphism emerges primarily during puberty when the individual goes through the pubertal transformation (103). Among adults, men tends to have greater arm muscle mass, longer and stronger bones and reduced limb fat, but a similar degree of central abdominal as females (101). In adult body size sexual dimorphism is best illustrated by stature where males are about 8% taller than females (79).

According to Prader (sited in Werner), longitudinal studies have shown that gender differences in height are built up by four components of growth (Table 3) (79) even if this difference varies between populations (101).
Boys and girls grow with somewhat different patterns. From birth, boys are longer and heavier than girls in all ages except for a year or two around 12 years. After girls have their menarche at around 12 years, they generally grow another 8 cm (or as much as 10 cm) and reach their final height at the age of 16–18 years. At the age of 12–13 years, the boys start to accelerate their height growth and reach their final height at an age of 18–20 years (29,104), even if some late maturers keep gaining height up to 23–25 years (105). The result is a mean value for the final height of about 180 cm for Swedish males and 167 cm for Swedish females (104,106).

Growth among boys is believed to be more responsive or plastic than among girls in regards to environmental factors. In good times boys grow relatively faster, but in harder times the boys growth is more affected (1,51,107), however, Kuh et al. (1991) does not find the evidence for male plasticity convincing and looks for other explanations (51).

<table>
<thead>
<tr>
<th>Differences in pre-pubertal growth-velocity. Boys grow faster than girls before birth and during their first year of life.</th>
<th>+ 1.5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longer pre-pubertal period of growth among boys. Boys get their peak velocity in height about 2 years later</td>
<td>+ 6.5 cm</td>
</tr>
<tr>
<td>More intensive peak height velocity during puberty for boys.</td>
<td>+6.0 cm</td>
</tr>
<tr>
<td>More growth for girls after the pubertal peak height velocity period</td>
<td>-1.5 cm</td>
</tr>
<tr>
<td>Difference</td>
<td>+12.5 cm</td>
</tr>
</tbody>
</table>

*Table 3. Differences between boys and girls in growth (79).*
1.3 Ecology

1.3.1 Overweight and obesity
Overweight and obesity among children and adolescents are considered a worldwide public health problem. The first indication that overweight and obesity were taking on epidemic proportions originated in the USA and Europe (108), where adult obesity has been reported to rise since the 1960s and among children after 1980 (3). During the last 50 years, the prevalence of obesity and overweight has increased almost in an unlimited manner (108), and overweight and obesity are also reported to increase in both developed and developing countries (109).

The World Health Organization (WHO) has declared overweight and obesity as one of the most serious public health challenges on a global level in the 21st century, in 2016 more than 340 million children and adolescents age 5–19 years were reported to be overweight or obese (110).

In Sweden the prevalence of overweight and obesity among children and adolescent has increased in the last decades. In an eight year period from 1973 to 1981 among 7 to 18-year-old Swedish children and adolescents, the severity and prevalence of overweight and obesity increased (111). According to the International Obesity Task Force (IOTF) references (112), the prevalence of overweight (including obesity) among Swedish 9-year-old boys was 12.3% and for girls 17.0%, for 15-year-olds, prevalence of overweight (including obesity) was 12.1% for boys and 11.15% for girls (data collected 1998–1999) (6). Another study, based on the data from the Swedish part of the WHO Childhood Obesity Surveillance Initiative (COSI), according to the IOTF reference (112), the prevalence of overweight and obesity of 7–9 year-old Swedish schoolchildren (born 1998–2001) was 16.1% and 2.5% for boys and 17.2% and 3.5% for girl, respectively (113).

However, some studies indicate a levelling of overweight prevalence among children and adolescents in several high-income countries (114-116). In the western part of Sweden a decrease of obesity among girls from 2000–2004 from 19.6%–15.9% (using the IOTF growth reference, 2000 (112)) was found, however, the decrease of obesity was not found in other areas of Sweden (117). If the reported decrease or plateauing of obesity is a temporary situation or a real change over time is yet to be determine.
1.3.2 Prognosis of overweight and obesity

Childhood obesity is associated with adult obesity (118-120). A 40-year follow up study by Mossberg (1989) on 504 overweight children found that the degree of obesity in the family and the degree of overweight in puberty, were the most important predictors of adult overweight (121). In an earlier study, partly based on the same sample as Paper III and IV in this thesis, among children born in 1981, the predictors for overweight and obesity from birth to age 16 years for girls and 18 years for boys, were explored. Weight at 12 months was associated with overweight at 16 years for girls and 18 years for boys. Weight gain between 18 months and 4-years was the strongest risk factor for being overweight in late adolescence for both boys and girls. For children with low birth weight (< 2500g) and high birthweight (> 4500g), there were no associations with being overweight or obese at 16 years for girls and 18 years for boys (122).

A substantial amount of literature published in recent years has shown that overweight and obesity can cause major health problems among adults (4,123,124). Additionally, among children and adolescents overweight and obesity can create serious health problems (4,120,125). Overweight and obese individuals are more likely to develop cardiovascular diseases, hypertension, diabetes, musculoskeletal disorders and some cancers such as breast cancer, ovarian, prostate, liver, kidney and colon cancer (120,126). In addition some studies have found that childhood obesity can have a profound effect on social and emotional well-being and self-esteem (127,128).

1.3.3 Underweight/thinness

When describing a situations of undernutrition indicators such as stunting, and wasting, underweight and thinness are used. Stunting refers to length-or height-for-age below -2 standard deviations (SD) (129). Stunting among children is the result of circumstances such as poor intrauterine conditions and insufficient nutrient supply and intake in the first 2-3 years of life. Unless the nutrition situation is restored, the individual will not reach biological potential for height (61,74,130,131). Wasting is weight for height below the -2 SD (129), and wasting in children is a symptom of acute undernutrition and is often a consequence of diseases (129). Underweight is weight-for-age below the -2 SD (129), and the result of undernutrition (129). Thinness is defined as low BMI for age. Three degrees of thinness are frequently used, thinness grade 1 as BMI 18.5 kg/m², thinness grade 2 as BMI 17 kg/m² and thinness grade 3 as BMI 16 kg/m² at age 18 (132), is primarily caused by undernutrition.
Even if underweight (low weight for age) or thinness (low BMI for age) among children and adolescents in affluent countries have not received the same attention as overweight, there are some studies exploring thinness (132-138).

The trends in prevalence of thinness among European and American adolescents from 1998–2006, based on self-reported height and weight, showed that prevalence of thinness (defined as BMI <17kg/m² at 18 years according to reference from IOTF (132)), was higher among 11-year old boys and girls compared to 13- and 15-year-olds. The prevalence of thinness among boys ranged from 0.2% for Swedish 15-year-olds (1998 survey) to 6.9% in Belgian-Flemish 11-year-olds (2002 survey), and among girls, the prevalence ranged from 0.8% in US 15-year-olds (2002 survey) to 8.8% in Belgian-Flemish 11-year-olds (2002) (136).

The prevalence of underweight among 9-year-old and 15-year-old Swedish schoolchildren accordingly, was 4.8% for boys and 3.5% for girls, and 3.5% for boys and 5.1% for girls, respectively (6), the cut-off point used was the age-adjusted 10th percentile according to references from Lindgren et al. (139).

1.3.4 Weight loss
In Sweden among children and adolescents aged 7–18 years weight loss, especially among girls increased in a period of 8 years among those born in 1973 and 1981. The weight loss was identified among obese, overweight, normal weight and underweight individuals (5).

In general, the causes of weight loss can be the result of disease, unhealthy or healthy behavior (140). As a part of the internalising of thin as a social standards of attractiveness may also contribute to body-image disturbance (141), dieting and unhealthy weight control (140), body dissatisfaction (142) and potential eating disorders (141,142). A meta-analysis found an overall elevated mortality rate for individuals with eating disorders such as anorexia nervosa, bulimia nervosa and eating disorder not otherwise specified (EDNOS). Mortality was highest among those with anorexia nervosa, and the annual mortality was 5 per. 1000 person-year with a slightly increase in studies of only females. Among individuals with EDNOS the annual mortality was estimated to 3 per 1000 person-year and bulimia nervosa was estimated to 1.7 per 1000 person-years (143).
1.3.5 Prognoses of underweight/thinness

The intrauterine conditions and connection to health and disease later in life, described among others by Barker or better known as the “Barkers hypothesis”, are well known (144), even if some criticism has been raised (145,146). In short, the Barker hypothesis states that individuals with low birth weight or short at birth were found to have an increased rate of coronary heart diseases as adults (71,94,144,147,148). Thinness or underweight can cause considerable health problems and may produce unfavourable health outcomes such as nutrient deficits, risk of osteoporosis, anaemia (149), decreased cognitive work capacity, menstrual irregularities and increased rate of infections (150).

1.3.6 Nutrition

Norgan (2012, p. 124) defines nutrition as “the process of whereby living organisms take in and transform extraneous solid and liquid substances necessary for maintenance of life, growth and the normal functioning of organs and the production of energy” (48). The nutritional status is the net measure and represents the energy that has been used for growth once the demands for maintenances for work and play and resistance to disease have been satisfied (2). The nutritional status of a population is usually measured by the physical growth of infants, children and young people (2,13,48). During the first year of life the infant grows rapidly and breastfeeding is recognised as the appropriate method of feeding new-borns and infants in the first months of their life. The World Health Organization (WHO) has recommended exclusive breastfeeding for about 6 months (151). The benefits of breastfeeding are well known (152,153). Breastmilk contains all the essential nutrients, however in the Nordic countries vitamin D supplements are recommended for infants of varying ages (153).

The nutrition recommendations in Sweden are basically the same for children (from 2 years), adolescent and adults, where a diet consisting of vegetables, fruit, berries, pulses, fish and seafood are recommended, and a reduced intake of processed food, red meat, sugar-containing beverages and salt (153). The daily recommendation of fruit and vegetables intake for 4–10 years is 400 gram/day, from 10 years to adulthood tare 500 gram/day (154).
1.3.7 Malnutrition
Malnutrition means simply bad nutrition, and applies equally to overnutrition as to undernutrition, but tends to be used more for the latter than the former (48). The first measurable characteristic of nutritional status is birthweight influenced by the mothers’ nutritional status and the foetus intrauterine life (1).

If a child’s nutritional status is inadequate because of insufficient food intake, the effect of disease (2,13,29,48,74), or lack of a supporting and caring environment, the child’s growth will be affected. Either the child will not grow at all or less than it would under more favourable circumstances (2,29). The short and long-term health consequences of undernutrition among children from low-income or middle-income countries are thoroughly described elsewhere (61,74,130).

According to WHO, most of the world’s populations live in countries where mortality due to overweight and obesity exceeds mortality due to underweight (110). The dietary intake is a critical determinant of body weight where excess weight gain occurs when the energy intake exceeds energy expenditure over a prolonged period (4).

Too big portion sizes, a low intake of fruit and vegetables and fibre rich food, high intake of high density food rich in fat, sugar and salt are problems well documented in the development of overweight and obesity (4,6-8). Intake of sugar-containing beverages have also been reported to contribute to overweight and obesity development among children and adolescents (8,155-158).

1.3.8 Dietary surveys
Dietary intake estimation encompasses the collection of information of the quality, amount and frequency of foods eaten or defined parts of these aspects. They can provide information on meal frequency or composition, or be used for calculation of energy and nutrient intake. Dietary information can be collected at different levels, as food supply data, household level and on individual level, where food supply reflects foods available or consumption data, household data on purchases, storage and use of foods. Data on the individual level provides information on average food and nutrient intake and their distribution in well-defined groups or individuals (159). Data on individual level can also provide an estimation of the adequacy of dietary intake and meal distribution and other aspects needed for studying the relationship between health and diet (160).
Two methods frequently used to collect dietary intake data on individual levels are short term and long term dietary assessments. In the short term dietary assessments, the intake from the previous day (24-hour recall) or records of the intake of food and drinks over one or more days (dietary records) are used. In the 24-hour recall method, a preferably experienced investigator interviews the respondent to enumerate the quantity of food and beverages consumed the previous day (159), or the same information is gathered by using a questionnaire. Weaknesses with regards to 24-hour recall, the respondents answer depends on memory, portions size is difficult to estimate and it is not possible to get information on the overall food and beverage intake because the diet varies from day to day (159).

In dietary records, the respondent records, often for three or four consecutive days, the food and beverages consumed. The food and beverage intake are quantified by weighting or estimated by cups or tablespoons. This method can provide a quite accurate data, on the other hand, the participants must be highly motivated because the participant burden is high (159).

In long-term dietary assessment methods the aim is to collect information on usual food intake from the previous months or year (dietary history or food frequency questionnaires) (159). In food frequency questionnaires (FFQ), the respondent is asked for the usual frequency of consumption of food listed in a questionnaire for a certain period in the past or for a normal week or month. The development of the food list is crucial to a successful and reliable data collection. A comprehensive FFQ generally includes between 50 to 150 food items and can be used to estimate a broad range of nutrients. When using a brief FFQ, the focus is on the intake of one or several specific nutrients, food items or beverages. Some of the weaknesses with FFQ are difficulties to remember food patterns in the past, and quantifying of food intake may be inaccurate because of poor estimation of recall portions and limited possibilities for food specification. Furthermore, the FFQ is not open-ended, which means that foods of importance may be absent (159).

1.3.9 Assessment of food intake in children
Methods used to explore food habits among children are mostly 24-hour recall interview or questionnaire (6,12,161), dietary records over four consecutive days (162) and food frequency questionnaires (7).

There are some obvious challenges when assessing food intake among children. It depends on the child’s age, cognitive development and the child’s
ability to remember and recall and estimate their food intake. For children under the age of 10 years, it is recommended that the parents or guardian assist the child or respond on behalf of the child. Depending on the individual child, a 24-hour recall interview or questionnaires’ can normally be applied to children from age 10 years and older. From about the age of 12 years food frequency questionnaire may be an alternative (159).

However, an accurate assessment of both quantitative and qualitative food intake among children is difficult. Livingstone et al. (1992) found that reporting on food intake was heavily influenced by the intelligence and the motivation of the respondent, the complexity and regularity of food patterns and the age at which the child could reliably report their low food intake in settings not controlled or under observation from adults (163). Among overweight or obese individuals, dietary surveys might be related to a higher degree of under-reporting (164,165). Social desirability and social approval may be important and intake of energy dense food and food rich on fat may be underreported (166). In a study among a group of Swedish 8 and 13-year-old children, Samuelson found that the children were able to provide an acceptable picture of their consumption of a single meal in a dietary recall covering the past 24 hour (12).

1.3.10 Meals and meals patterns
A meal could be defined as food eaten as part of a structured event (167), where eating contributes to ordering the day into segments of morning, mid-day, afternoon and evening (168).

Every society has norms and conventions that traditionally regulated eating and rules regarding what is classified as edible foods, how foods should be combined into dishes and meals, how meals are to be ordered with respect to place and social company (169).

In the Scandinavian countries, Denmark, Finland, Norway and Sweden meal pattern consisting mainly of 3–5 meal events per day, with breakfast, lunch, and dinner as the three most common meals (168).

With better economic times, the meal patterns have changed in the sense that more meals are eaten outside the home. Even so, a majority of meals are still eaten at home (169) with the exception of mid-day meals which are consumed in kindergarten or school by the children and at the workplace by the adults (170).

Even if the majority of meals are eaten at home, it does not mean that meals, especially in the afternoon, are consumed with all of the family members present (170,171). It seems that eating together is more dependent on
the number of adults in the family than if there are children present in the family. Further on, it is not uncommon that some of the household members, children or adults, are absent from family meals due to leisure time, afternoon activities or work, in fact, the notion of “the family” meal with all the members eating at the same time often occurs not on a daily basis but on every-other-day-basis (169). From 1997–2012 eating at the dining table declined in Denmark, Norway and Sweden between 9 to 14%, while eating at coffee or sofa table increased (171). Of the meals eaten at home, children and adolescents eating in front of the television alone was associated with poorer dietary qualities (172,173).

There is currently a large body of evidence supporting the importance of specific food patterns or dietary patterns in maintaining good health (11,153,174). With regards to establishing food habits among children it is up to the parents to regulate and socialise the children’s food habits (10,175). A number of factors have been suggested to contribute to healthy meal habits among children, for example the family attitude towards meals. When the mother considered the meal situation as quality time with the children there was a better food quality compared to families where the meals had a lower status (175). Additionally, it is suggested that family meals and a positive environment for the family meals are positive with regards to preventing eating disturbance (176).

Children’s and adolescents eating behaviour is strongly influenced by the family environment, such as parents’ own eating behaviour and child feeding practice (9,177,178). The parents can create environments that form the development of healthy or unhealthy food habits among the children, by introducing healthy food items such as vegetables and fruit or restricting food items like high dense food items or sweets (9).

Even if the majority of meals is eaten at home, eating out at restaurants is more common (179) also among families with children (178). Among adults, eating at restaurants is reported to have a potentially negative health consequence because of a higher average calory and fat intake, and lower fruit, vegetable and fibre intake (180). Additionally, frequent eating high fat and high sugar foods at fast-food restaurants can contribute to the development of overweight and obesity (181).

1.3.11 Breakfast
In the Nordic countries, the first eating event of the day is usually breakfast, eaten before 8 AM on weekdays, and somewhat later on weekends. With
regards to food items and beverages consumed at breakfast, there are similarities between the Scandinavian countries. A Swedish breakfast usually consists of open sandwiches, breakfast cereals, yoghurt, milk or juice, in Norway the breakfast consists of open sandwiches with milk, juice or water, in Denmark, open sandwiches, breakfast cereals and milk, and in Finland open sandwiches, porridge, milk, juice or water (182).

Children and adolescents’ breakfast habits have been described as being of importance for the overweight and obesity status, and having breakfast is recommended in the Nordic countries (7,153). In 2010, 72% and 66% age 11, 13 and 15 years old Swedish boys and girls, reported a daily breakfast intake (10). However, children and in particular adolescents are more likely to skip breakfast than any other meal (174). Regular breakfast consumption has been associated with positive health benefits (10,11), and a positive effect on school performance where breakfast consumption was most evident on measures of memory and in terms of fewer errors on attention tasks (183). Children who regularly have breakfast have been shown to be more likely to have a better diet quality and a higher intake of key food groups, such as fruit, dairy and dietary fiber. Furthermore, they are more likely to meet the recommendations for micronutrients (184).

Children who skip breakfast tend to eat more energy-dense food such as fast food and consume a higher percentage of energy at subsequent meals. When children are skipping breakfast, it can lead to excess hunger, overeating and consequently, in eating larger portion sizes (11).

1.4 How to describe growth

1.4.1 Relative weight
The anthropometric measurements express body size and composition, and reflects inadequate or increased food intake, insufficient exercise or disease. Information such as those regarding underweight/thinness and different degrees of overweight, and even normal weight are obtained from measures of height and weight (185). Additionally, there are other methods for measuring body fat among individuals such as skin fold thickness (186), dual-energy X-ray absorptiometry (DXA) (187) or ultrasound (188). However, measurement of height and weight are an inexpensive and non-invasive method to assess the size, and proportion of the human body (185).

For height measurement of children about 2 years and younger, the child is placed supine on a measuring board, and the height is reported to the nearest 0.1 cm. The height of children older than about 2 years is measured
by making them stand straight on a flat surface, wearing no shoes, using a metric rule attached to the wall and headboard that can be brought into contact with the upper point of the child’s head. The heights are recoded to the nearest 0.1 cm (185).

The measurement of weight for the infant and toddlers should be made without clothing or diaper, using a calibrated scale. The measurement is reported to the nearest 0.1 kg. Weight among children old enough to stand without support are measured by making them stand with light clothes, no shoes and preferably no jeans or sweaters, using a calibrated weight. Weight is measured to the nearest 100 gram (185).

Among humans there is a loss of height from morning to night because of compression of the spinal column (189,190). Ideally the children should be measured at the same time of the day, preferably in the morning, after emptying the bladder.

Height and weight, by definition are clear measures (79). However, relative weight is more complicated especially among growing subjects (79,191). It is difficult to express relative weight by using weight and not height as dependent variables (79).

In an effort to quantify a person’s life course weight and height, starting from the premise that “the transverse growth of man is less than the vertical”, Quetelet (1832) proposed that among adults, normal body weight was proportional to the square of the height in meters, the Quetelet index (31), which was later renamed the Body Mass index (BMI) (32). Benn formulated the Benn Index which is the general form weight divided with height$^n$, (weight/height$^n$) (192).

Cole introduced the use of BMI (weight/height$^2$) for children (193). Even if BMI has some well-known challenges, for example it fails to distinguish between fat mass and muscle mass (3,194,195), BMI is still widely used and considered as a convenient measure (3). BMI needs to be adjusted for age and its expected value changes substantially during childhood, especially in infancy and puberty (191). Therefore, Cole suggested that during puberty a larger power is required, where weight/height$^3$ (W/H$^3$), also named Tri-Ponderal Mass Index/Rohrer’s Index is better (193). Additionally among newborns the first weight is often expressed in Tri-Ponderal Mass Index/Rohrer’s Index (196). This is because of the body proportions of new-borns, with relative large head and torso and short extremities.
1.4.2 Canalization and catch-up growth

The phenomenon of canalization was described by Waddington (1957, p. 19) as:

“the most favourable path”; that is to say if a mass of material is developing along one such path and is at some time during the course of development forced out of it by some experimental means, it will exhibit some regulative behaviour and tend to return to the normal path. To express this character I have spoken of such paths as being “canalized” or “buffered” (197).

It is most likely that this canalization of a favourable path is genetically determined and that growth is target seeking in the sense that we have a genetic potential for adult stature (198). At the age of 2–3 years the child will find and stabilise growth in its individual channel of BMI over age and remain there, and the process of growth take us inexorably towards our genetic potential. Some will be pushed out of their path due to starvation or illness, but there are regulative forces that tend to return growth into the original channel when the situation returns to normal (29,49).

After recovering from situations where growth is slowed down, for a period the individual will grow faster than before, and the growth velocity increases to above normal for the individuals’ age and maturity, this is called the “catch-up growth”, a phenomenon described by Prader (49). If an individual achieves total or partial catch-up, depends on the timing, severity and duration of the insult (29,74,130,198,199).

Three types of catch-up growth have been suggested. The first type of catch-up growth is often seen in infancy and childhood, when the growth restriction ceases and height velocity increases up to 4 times the mean velocity for chronological age. Once the original curve is reapproached, height velocity returns to normal. The second type is when growth restriction ceases, the delay in growth and somatic development persists. The growth has no or only a small impact on the height velocity but the duration of growth continues longer. The third type is a mixture of the previous two: when growth restriction ceases, there is an increase in height velocity as well as a delay and a prolonged growth (200). However, theories about the mechanisms behind catch-up growth are discussed (200,201), and the phenomena are still poorly understood.

1.4.3 Growth standards.

According to Healy, “Perhaps the most basic question relating to human growth in clinical practise is simply, “is this child normal?” with respect to
whatever aspect of its growth is being studied” (202). Using the term normal introduces at least two challenges. Is normal to be regarded as a standard that is desirable (prescriptive) and may well be difficult or not achievable, or is normal referring to what is most common or ordinary in the sense of what is most commonly occurring in a group or population (descriptive)? In human growth, the term normality is most widely used in regards to what is most commonly occurring within a population. The normality of a particular child is assessed by the frequency of occurrence of that particular value of the measurement in a standardising group, a group of children who are normal by definition (202). In order to monitor the individual child’s growth, a growth standard is an appropriate method (203).

A growth reference is a statistical summary of anthropometric measurements of different individuals at different ages. The statistical summary often involves the mean and standard deviation, or the median and selected centiles for age and genders (204). This descriptive approach describes how individuals grow in a defined period in a defined group (205), and can be applied to other children to establish whether or not the child’s measure is typical or not of the reference population (204).

A growth standard is essentially the same as a growth reference except for the underlying reference data is selected on health grounds (204), where such a prescriptive approach aims to describe how children should grow (205) rather than how they grow.

A growth chart is a growth reference presented in a visual display for clinical use which display both the size of a child at various ages and their growth rate and velocity over time, based on the slope of the curve (204).

1.4.4 Comparative growth studies, methods and standards
Growth studies are potentially powerful tools when it comes to monitoring the health of a population as a whole but also on subgroups in a population where economic or social benefits are less than they should be (1).

1.4.5 Growth standards. The use of cross-sectional and longitudinal samples
In general there are three types of materials commonly used for growth studies, cross-sectional data samples, longitudinal data, and sometimes different samples put together as pooled samples or mixed longitudinal samples (29,206).

In cross-sectional studies, the individuals are measured once and information on height and weight at a given age are noted. Cross-sectional surveys are widely used because they are cheap to carry out, data are achieved
quickly and often include a large number of individuals. However, cross-sectional data give no information on the rate or velocity of growth or on the timing of particular phases such as adolescent’s growth spurts (29).

In longitudinal studies, each individual is measured periodically, often over several years. In order to get information on velocity standards, it is necessary to have at least two measurements of the same individual. However, there are some well-known challenges with longitudinal studies. They are expensive to conduct and it takes a long time to collect data. Another problem is drop-outs, it is almost impossible to maintain all individuals in a cohort over a long period of time because of inevitable drop-out occurring during the study (29).

A third option is mixed longitudinal samples (206), where different, individuals at for example ages 3–5, 6–8, 9–12, 13–15 and 16–18 years are followed for three years, in order to get information from age 3 to 18 years. A fourth option is to pool various samples (112) which makes the transparency difficult, and understand what the reference represents.

When constructing a growth standard, a nationally representative longitudinal complete sample with height and weight from birth to adulthood is preferable (79). When a longitudinal sample is collected it is possible to convert the sample from descriptive to prescriptive by excluding groups, depending on the aim of the growth curve. A longitudinal material captures differences in the growth tempo and variations in puberty and velocity standards (29). However, nationally representative longitudinal data are rare but cross-sectional samples are widely used.

### 1.4.6 Growth references around the world

There are three widely used growth references, the World Health Organization (WHO) growth references for 0–5 years and from 5 years to 19 years, the growth reference from the International Obesity Task Force (IOTF) and the Centers for Diseases Control and Prevention (CDC).

### 1.4.7 Growth references for pre-school children from WHO

In 2006 WHO released new growth references for children from birth–5 years based on length/height, length/age and weight/age expressed in percentiles and z-scores. The sample consisted of healthy breastfed infants and young children raised in an environment that did not constrain growth. The final sample consisted of a mix of longitudinal and cross-sectional data from six countries, Brazil, Ghana, India, Norway, Oman and USA. The longitudinal component was mothers and new-borns screened and enrolled at birth
and visited at home on week 1, 2, 4, 6 and thereafter monthly from 221 months, in the second year by monthly measurements. The cross-sectional component consisted of children age 18–71 months, measured once with the exception of Brazil and the USA where two or three times measured at 3-months intervals. The total pooled population consisted of 6,669 children (48% girls) (207).

1.4.8 Growth references for schoolchildren and adolescents from WHO
As a consequence of the implementation of the new WHO Child Growth Standards for preschool children, the need for curves for BMI expressed in percentiles and z-scores on a continuous scale from age 5–19 years was identified (208). The aim was to develop growth references for clinical and public health application. Due to problems with accessing appropriate data for construction of the new growth reference that would agree with the WHO Child Growth Standards at five-years of age, the original non-obese sample with expected height from 1977 National Center for Health Statistics (NCHS)/WHO growth reference was used for the new growth reference from age 5–19 years. The core sample for reconstruction was the NCHC sample which was pooled from three datasets. The first and second samples came from the Health Examination Survey (HES) Cycle II from 6–11 years and Cycle III from 12–17 years. The third sample was from the Health and Nutrition Examination Survey (NHANES) Cycle 1 using data from 1–24 years. The final sample for fitting height/age curves was 30,907 observations (50.3% boys), for weight/age curve 30,100 observations (50.3% boys) and for BMI 30,018 observations (50.3% boys) (208).

The growth references consists of the published per-month tables for genders, age 5–19 years, in the range from -3 to +3 standard deviations (SD) with median as the middle measure. The curves were constructed to accord with growth curves for preschool children and BMI cut-off at age 19, whereas +1 SD are BMI 25.4 for boys and BMI 25.0 for girls, while the +2 SD values are BMI 29.7 for both genders. Curves for percentiles of 1st, 3rd, 5th, 15th, 25th, 50th, 75th, 85th, 97th and 99th were also constructed (209). Cut-off for thinness was set at < -2 SD and for severe thinness < -3 SD (208,209).

1.4.9 Growth reference from International Obesity Task Force (IOTF).
The IOTF cut-off values from 2012 was an extension of the IOTF growth reference from 2000 (112) and 2007 (132). The growth reference was based on six nationally representative cross-sectional surveys from Brazil, Great Britain, Hong Kong, the Netherlands, Singapore and the United States with
age ranging from 6–18 years, with a total sample of 192,727 individuals (49% girls). Because of missing data after 18 years in the Hong Kong sample, the final age was set at 18 years. Four of the data sets were based on single samples while the British and the United States consisted of pooled samples collected over a period of time. The reference values are per-months values for BMI of 16, 17, 18.5, 25, 30 and 35 kg/m² at 18 years and extrapolated back from 18 to 2 years. In the extended IOTF references it is possible to express BMI as centiles (for example obese girls, BMI 30 kg/m² at age 18 = 98.6th centile) which makes comparison with other BMI references easy (138). According to the authors of the extended version (138), comparing the old (132,210) and extended IOTF (138) cut-off the differences were minimal except for thinness grade 2 and 3 for children under age 6 where a slight discrepancy could appear (138).

1.4.10 Growth reference from Centers for Diseases Control and Prevention (CDC).

The growth reference from CDC was released in 2000, based on a revision of the 1977 growth reference. The 2000 CDC is recommended for use in both clinical practice and research to assess growth and size of infants, children and adolescents. Charts provide weight-for-age, height-for-age and BMI-for-age for infants from birth to 36 months and for children and adolescents age 2–20 years expressed in percentiles. The growth curves are constructed on the basis of five large cross-sectional samples of U.S children (211).

1.4.11 National growth references/growth charts

Several countries have national growth references for height and weight (212-224). The data on which the respective growth references were based on vary in size and sampling methods, where the most common were cross-sectional samples, repeated cross-sectional samples or pooled samples. It also varies if the samples were nationally representative or local samples from geographically restricted areas. Growth references based on nationally representative longitudinal samples are rare, however one such growth reference is the new Swedish growth reference by Werner (212). In order to illustrate the vast differences in the construction of the growth references, the ones from Scandinavia were chosen. In addition the growth reference from Great Britain, because of their long tradition in growth references and the Netherlands because of its unique four nationally representative samples over time were chosen.
1.4.12 Swedish growth references
In Sweden there are two widely used growth references, one based on local data from Göteborg (the growth reference from Karlberg et al.) and the other one based on national data (the growth reference from Werner).

1.4.13 Karlberg et al.
In 2001, Karlberg et al. (224) published growth references with BMI for age are expressed in z-scores for both genders aged 0–18y. For age 0–1.5 years the BMI reference values are available for quarterly intervals (0, 0.25, 0.5, 0.75, 1.0 and 1.5 years), and annually from ages 2–18 years. The growth references are based on 3,650 individuals (51% boys) from the Göteborg area in the south-western part of Sweden. Most of the children were born in 1974 (76.8%) and 1973 (16.7%), 3% were born before 1973 and 3.5% born in 1975. From the eligible population of 5,111 individuals, 174 individuals (55.7% girls) were not willing to participate and 449 individuals (49.4% girls) failed to attend the investigation in school.

From April to November 1992 in the last grade of school, height and weight were measured by trained personnel using standardised procedures and calibrated equipment. In addition, health records from birth to the last grade of school were obtained. Individuals with missing records (529 individuals) were excluded, which was also the case for individuals with growth related disorders and some other problems (303 individuals) were excluded (225).

1.4.14 Werner
In 2011, the new Swedish national references by Werner (212) were published. The reference values from birth to 19 years, with monthly BMI, weight (kg) and height (cm) and BMI for age are expressed in z-scores.

The references provide normative values, building on a nationally representative sample of 3,107 children (50% girls) born in 1981, with longitudinal data collected from child health care records and school health records, with few missing cases (1.6%). Individuals with birthweight below 2500g (118 individuals), born outside of Sweden (239 individuals) and with diseases or conditions of major impairments for growth (42 individuals) were excluded (79). The statistical methods have been thoroughly described previously (226).
1.4.15 Norway
The Norwegian growth references were based on a cross-sectional sample from Bergen in the western part of Norway. Growth curves for weight, height and BMI expressed in percentiles are divided into different age intervals for children between ages 0–19 years for both genders (227).

The data was collected from 2003–2006 for the Bergen Growth Study, which included 8,299 children ages 0–19 years. After excluding 1,008 children (936 children with one or both parents born outside Northern Europe, 85 children with chronic disease or prematurity), the total sample consisted of 7,278 children (51% boys). Height and weight were measured by trained personnel using standardised technique (213).

1.4.16 Denmark
The Danish growth reference is based on data from three population based studies. Growth curves for height, weight and BMI from birth to 20 years for both genders expressed in z-scores (228).

The Copenhagen Puberty study is a combined cross-sectional and ongoing longitudinal population-based cohort of schoolchildren in the Copenhagen area born 1987–2002. The individuals were examined between 1991–1993 and 2006–2008 (age 5.9–9.9 years at examination). From the cross-sectional and longitudinal sample a total of 1,118 individuals (59% girls) were included. The ongoing mother-child cohort includes individuals born from 1997 to 2002, and information on the heights of 1,792 individuals (55% boys) were included.

The third sample was a prospective “cross-sectional cohort study” of young men age 18–20 years collected in 1996 and 2006. Information on height and weight of 2,723 men were included. After exclusions the total sample consisted of weight and height measurements of 7,385 individuals (28% girls), which weight were measured by health professional or trained personnel (214).

1.4.17 Iceland
The growth references from Iceland are based on cross-sectional studies of 6,500 schoolchildren (49% girls), measured in 1983–1987. The growth charts for height, weight and expressed in percentiles for individuals 6-20 years (215).
1.4.18 Finland
The Finnish growth references are based on mixed cross-sectional/longitudinal data on individuals from birth to 20 years from the second largest city of Espoo in the southern part of Finland. Data was collected in 2003–2009 of individuals born in 1983–2008, and the sample for weight references included 73,459 individuals and for height references included 26,636 individuals. Growth curves for weight, length and BMI for age are expressed in z-scores (216).

1.4.19 The UK
Since the first growth reference for British Children was developed by Tanner-Whitehouse and published in 1959, several modifications and revisions were made over the years (229), which ultimately resulted in a confusion on which growth reference to use. Based on the recommendations from the Growth Reference Review Group the growth references used in UK today are, UK90 (UK 1990) reference for height, weight and BMI which are recommended for use in all ages (230). The UK90 consist of 17 distinct surveys, of longitudinal and cross-sectional samples, which are representative for England, Scotland and Wales, where 37,700 children from 23 weeks to 23 years (217) are measured. Growth curves for height and weight are expressed in percentiles and BMI in z-scores (231).

1.4.20 The Dutch surveys
The Netherland growth references is derive from four consecutive nationwide cross-sectional growth studies. The first nationwide growth study took place in 1952–1956, the second study in 1964–1966, and the third between 1978–1980 (99), fourth in 1996–1997 (232) and the fifth in 2009 (100). The 2010 Dutch growth reference are based on 12,005 children (52% girls) of Dutch origin, age 0–21 years. Growth curves for height, weight and BMI are expressed in z-scores (100,223).
2 AIMS

2.1 General aim
The general aim of this thesis was to investigate somatic growth, height and weight, and deviant growth patterns as weight loss and obesity among Swedish schoolchildren and how nutrition and other factors influenced growth.

2.2 Specific aims
Paper 1. To investigate the prevalence of thinness, normal weight, overweight, obesity and severe obesity using four growth references, two international and two Swedish national growth references.

Paper 2. To investigate breakfast frequency, intake of selected food items and beverages in relation to overweight. Furthermore to analyse breakfast habits and food/beverage intake in relation to parental demographic and lifestyle factors in relation to overweight and obesity.

Paper 3. To investigate if substantial BMI reduction of 10% or more, caused by either disease, healthy or unhealthy behaviour, in Swedish children and adolescents age 7–19 years has any impact on the final height. Furthermore, to investigate whether age or weight category at the start of the BMI reduction have any impact on the outcome measure expressed as final height.

Paper 4. To describe and compare the longitudinal pattern of body weight development at group level and individual level for ages 7–18, over time.
3 MATERIAL AND METHODS

3.1 Samples and data collection
The papers in this thesis are based on four samples. Two cross-sectional samples as part of the World Health Organization European Region Childhood Obesity Surveillance Initiative (WHO COSI) (Paper I and II), and two longitudinal samples (Paper III and IV), where the design and data collection for the 1973 cohort and 1981 cohort was done by Werner (79).

3.2 The Childhood Obesity Surveillance Initiative (COSI).
During the preparation for the World Health Organization (WHO) European Ministerial Conference on Counteracting Obesity in Istanbul, November 2006, it was noted that only a few countries had good, comparable and representative data on childhood overweight (233). The report demonstrated a general lack of data, from member states regarding the WHO European region on overweight and obesity prevalence. The report particularly expressed the lack of nationally representative data for the age groups of 6 to 9-year-old children on national level. Further on, the aim was to provide measured data on height and weight as opposed to self-reported data on height and weight (234).

The need was for standardized and European wide harmonized surveillance systems on which policy development within the European Region could be based was recognised. As a result, the surveillance of overweight and obesity prevalence was strongly recommended in the WHO report (4). This recommendation resulted in the development of the Childhood Obesity Surveillance Initiative (COSI), coordinated by the WHO Regional Office for the European Region (233).

A common protocol and manual for data collection were developed by some of the member states representatives at a meeting at Karolinska Institutet, Huddinge, in April 2007. Based on comments from member states and input from an expert meeting in Paris in June 2007, some adjustments were made, and the protocol was finalized in January 2008 (235).

The design for the study was repeated cross-sectional samples. The first data collection took place during 2007–2008 school year. In addition to Sweden, twelve other countries participated; Belgium, Bulgaria, Cyprus, Czech Republic, Ireland, Italy, Latvia, Lithuania, Malta, Norway, Portugal and Slovenia (233,235). Ten years later, at the COSI meeting in 2017, 35 European countries participated (236).
3.3 Paper I

3.3.1 Sample COSI 2008
The sample was cross-sectional, which meant that data for height and weight, was collected at one occasion (237). A random sample of 220 from a total of 3,064 schools was selected by Statistics Sweden from the National School Registry. Of the 220 selected schools, 94 (48%) agreed to participate and were included in the sample. The participating schools were found to be representative of the 220 selected schools and of all the primary schools in Sweden according to the geographical spread, type of municipality and area of education level (113). The schools were divided for data collection and management between Karolinska Institutet (northern and eastern Sweden) and Gothenburg University (western and southern Sweden) (113). The head masters of the schools were sent a formal letter of invitation and subsequently contacted by phone. After obtaining permission from the schools, a class list for the whole school was obtained, and sampling was performed with the classes as sampling units.

Children in Sweden start first grade in the school the year they turn seven. The data was collected in grades one and two during the second term of the school year. Among the 94 participating schools prior to measurements, invitation letters were sent to the parents of all children in grades 1 and 2, including an opt-out form for participation. Children gave verbal consent before measurements. In the 94 participating schools, 5,326 children attended 1\textsuperscript{st} and 2\textsuperscript{nd} grade, of which 4,538 (52\% boys) were measured. In total 788 children were not measured, 333 because of parental refusal, 368 children were not measured due to illness, absence or refusal on the day of measurement and 87 because birth date were missing or other reasons (missing 11\%) (113).

3.3.2 Data collection COSI 2008
The data was collected from May to July 2008. All measurements from one school were performed on the same day and children who were not present were registered as such. Trained staff measured the height, weight and waist circumference of the children using calibrated equipment and the standard COSI protocol. The children were wearing light clothing and no shoes. The height was measured to nearest 0.1 centimetre (cm) using SECA 214 portable stadiometer. The weight was measured to the nearest 0.1 kilograms (kg) using SECA 862 digital weight (235). Data was entered in a common template. BMI (kg/m\textsupersquare{2}) was also calculated. Furthermore, a school record form
(mandatory) was completed in an interview with a school representative (235) and a family record form (voluntary) was filled out by the parents (235,238).

### 3.3.3 Method

From a sample of 4,538 individuals, children younger than 6 years and older than 10 years (n=18) and 2 boys were excluded due to missing information on height, leaving a total sample of 4,518 (52.2% boys), age 7 (7.00–7.99), 8 (8.00–8.99) and 9 (9.00–9.99) years.

The individual child’s relative weight (BMI) was categorised according to four growth references, two international, the WHO (209) and IOTF (138) and two Swedish nationally used references, one from Karlberg et al. (224) and the other from Werner (212). Growth references from WHO (209) and Werner (212) had reference values for each month and for boys and girls, separately expressed as z-scores. The growth reference from Karlberg et al., expressed as z-scores, had reference values for each whole year (224). References from IOTF (138) had values for each month and were expresses as BMI 16, 17, 18.5, 25, 30, 35 kg/m² at 18 years and extrapolated back for each month back to 2 years (from 92–216 months). The BMI for each child was categorized according to thinness grades 1, 2 and 3, normal weight, and overweight, obesity and severe obese using four growth references (Table 3).

<table>
<thead>
<tr>
<th>IOTF</th>
<th>WHO</th>
<th>IOTF</th>
<th>Werner</th>
<th>Karlberg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thinness grade 3</td>
<td>≤3SD</td>
<td>*≤16</td>
<td>≤–3SD</td>
<td>≤–3SD</td>
</tr>
<tr>
<td>Thinness grade 2</td>
<td>&gt;–3SD ≤–2SD</td>
<td>&gt;16 ≤ 17</td>
<td>&gt;–3SD ≤ –2SD</td>
<td>&gt;–3SD ≤ –2SD</td>
</tr>
<tr>
<td>Thinness grade 1</td>
<td>&gt;–2SD ≤–1SD</td>
<td>&gt;17 ≤ 18.5</td>
<td>&gt;–2SD ≤ –1SD</td>
<td>&gt;–2SD ≤ –1SD</td>
</tr>
<tr>
<td>Normal weight</td>
<td>&gt;–1SD &lt; +1SD</td>
<td>&gt; 18.5 &lt; 25</td>
<td>&gt;–1SD &lt; +1SD</td>
<td>&gt;–1SD &lt; +1SD</td>
</tr>
<tr>
<td>Overweight</td>
<td>≥ +1SD &lt; +2SD</td>
<td>**≥25 &lt; 30</td>
<td>≥ +1SD &lt; +2SD</td>
<td>≥ +1SD &lt; +2SD</td>
</tr>
<tr>
<td>Obesity</td>
<td>≥ +2SD &lt; +3SD</td>
<td>**≥30 &lt; 35</td>
<td>≥ +2SD &lt; +3SD</td>
<td>≥ +2SD &lt; +3SD</td>
</tr>
<tr>
<td>Severe obesity</td>
<td>≥ +3SD</td>
<td>**≥35</td>
<td>≥ +3SD</td>
<td>≥ +3SD</td>
</tr>
</tbody>
</table>

*BMI for thinness grades 1–3 defined to pass through BMI 16 (kg/m²), 17 (kg/m²) and 18.5 (kg/m²) at the age of 18.

**BMI for overweight, obesity and severe obesity defined to pass through 25 (kg/m²), 30 (kg/m²) and 35 (kg/m²) at the age of 18.

Table 3. Range for thinness, normal weight, overweight, obesity and severe obesity for four growth references for BMI (138,209,212,224)
3.4 Paper II

3.4.1 Sample COSI 2010.
The second sample is a cross-sectional study and a sub-set of the COSI study. The COSI collection of 2010 represented 21 (47%) schools out of the 45 schools from the Eastern part of Sweden involved in the 2008 data collection. Data was collected according to the COSI protocol, and included the anthropometric data for height and weight, the school record form (mandatory) and family record form (voluntary) filled out by the parents.

The sample consisted of 1,083 individuals, of which 225 children were excluded because of missing information for age, height and weight. In addition 110 children younger than 6 years and older than 10 years were excluded, leaving a total sample of 748 children (boys 51%). The number of participants in the 2010 data collection was lower than that of the 2008 data collection. The reason for the low participant rate in the 2010 data collection was due to instructions from the regional ethics review board to ask for informed active consent from parents before gathering data, while the 2008 data collection included a passive consent from parents. Rather few signed consent forms were returned from the parents in 2010. This resulted in exclusion of remote schools, due to the smaller numbers of children to measure in each school.

3.4.2 Merged sample COSI 2008 and 2010
The sample collected in 2008 was merged with the sample collected in 2010. Data used was anthropometric data and the responses from the voluntary family record form. A total sample contained of 2,620 children (52% boys) (1872 children from the data collection in 2008 and 748 children from the data collection in 2010). The children in the data collection from 2008 were born during the years 1998–2001, and in the 2010 data collection during 2000–2003.

3.4.3 Data collection COSI 2010.
The data was collected from May to July 2010. The same anthropometric data collection procedure, as in 2008, was followed for measurement, using the same equipment. Data was entered in a common template. BMI was calculated.
3.4.4 Voluntary family record form for data collection COSI 2008 and 2010.

Optimizing diet and increasing physical activity are essential for combating the obesity epidemic (4). In addition to collecting anthropometric measures it was also important to collect information on the children’s dietary intake and physical activity. The voluntary family record form contained questions about the children’s physical activity pattern, breakfast frequency and intake frequency of selected food and beverages.

The questions asked for breakfast was; over a typical or usual week, how often does your child have breakfast? For food and beverages; over a typical or usual week, how often does your child eat or drink the following kinds of foods or beverages? The option for breakfast and for food and beverages were; every day, most days (4-6 days a week), some days (1-3 days a week) and never (235).

The COSI protocol contained 16 food and beverage items, with two alternatives for milk, low fat milk/semit skimmed milk and whole fat milk (235). The data from Sweden contained 17 food and beverage items since milk was divided into three categories, skimmed/semit skimmed milk, low-fat milk and whole fat milk.

The voluntary family record form also contained questions about the parents’ socioeconomic characteristics, such as education and household income and area of living. The question for parents’ education was; what is the highest level of education you and/or your spouse/partner have completed? The options for answer were, primary school, secondary school, undergraduate/bachelor degree or master degree or higher. For household income, the question was; during the past calendar year, what was the gross income of your household? The respondents were asked to express yearly income in the local currency (235). The areas of living were divided into three categories, urban, semi-urban and rural. The degree of urbanization was classified according to a European reference (239). Urban was defined as densely populated areas including at least 50,000 inhabitants in continuous local living areas with more than 500 inhabitants per square kilometre. Semi-urban was defined as a continuous set of local areas with more than 100 inhabitants per square kilometre or with a total population of at least 50,000 inhabitants or adjacent to a densely populated area. Rural was defined as a thinly populated area not belonging to urban nor semi urban areas (239,240). Parents were also asked to self-report on height and weight. Their BMI was calculated and parents weight were classified as thin (BMI ≤18.5), normal weight (BMI>18.5 <25), overweight (BMI ≥25<30), and obesity (BMI≥30) (185).
The parent questionnaires were given to the children at measurement day to take home and be completed by the parents or caregiver, if possible with the child (233).

3.4.5 Method
The relative weight (BMI) of all children was categorised as thin (≤ -1SD), normal weight (>-1SD<+1SD), overweight (≥+1SD<+2SD) or obese (≥+2SD) according to the Swedish national growth reference by Werner (212).

Breakfast consumption and food and beverage intake for the four alternatives, every day, most days (4–6 days), some days (1–3 days), never.

To facilitate the identification of factors of relevance for overweight and obesity, the outcome variable used was overweight (including obesity). Children who were categorized as thin (n=425) were excluded from the chi-square and the regression analysis. Response on independent variables such as breakfast intake were dichotomized into every day and less than 7 days a week, response of food and beverage intake were dichotomized into less than 4 days a week and 4 days a week or more.

Regarding sociodemographic categories, parental education was dichotomized into one or both parents’ university education and below university education, area of living into urban/semi-urban and rural. Additionally, parents’ weight status was dichotomized into normal weight and one or both parents overweight/obese.
3.5 Paper III

3.5.1 Sample 1973 cohort
The study population was every child born in 1973 on the 15th of every month living in Sweden 31.12.1989, according to statistics Sweden (1999) a total of 3,749 children. The number of children whose data were collected were 3,579 (52% boys), from age 7 to 18 years. Of the included children, 225 were born outside Sweden. Individuals from all of Sweden were included.

An experienced paediatrician assessed the child’s medical status based on information from the child health records. As a result of the assessment, 32 children with disorders or major impairment growth were excluded. The diagnosis for the children are available in a previous publication by Werner (79).

3.5.2 Data collection 1973 cohort
In Sweden, almost all the children attend school between the ages 7 to 19 years. During this time, information on growth, height in centimetre (cm) and weight in kilo grams (kg) are recorded on a fairly regular basis by school nurses.

The data was collected from school health records, in both public and private schools. The data collection took place in three waves, the first wave when the children were 16 years old, the second when they were 18 years old and the third wave was looking for records in local community archives after the adolescents had left school. Each school health record was given a unique study identification code number by school nurses. The health records were collected from 3,579 individuals out of 3,749 eligible, meaning there were only 170 (4.5%) missing health records (79).

After excluding 32 children with disorders or major growth impairment, and 17 children (7 boys and 10 girls) with fewer than two measurements, the total sample for the 1973 cohort were 3,530 (52% boys) (79).

3.5.3 Sample 1981 cohort
The study population was every child born on the 15th of every month in 1981 and living in Sweden 31.12.1989, which were, according to Statistics Sweden (1999), 3,158 children.

The number of children in the sample were 3,107 individuals (50% girls) from birth to 19 years. Of the included children, 239 were born outside Sweden. Individuals from all counties in Sweden were included.
An experienced paediatrician assessed the child’s medical status based on information from the child health records. As a result of the assessment, 24 children with disorders or major growth impairment were excluded. The diagnosis for the children were available in a previous publication by Werner (79).

3.5.4 Data collection 1981 cohort
From birth to the children start school, almost 100% of Swedish children visit child health centres, where they are weighed and measured by health professionals. The children’s health records are transferred to school health nurses when the children start school. Almost all children stay in school from 7 to 19 years, and they are weighed and measured by school nurses on a fairly regular basis. If a school health nurse is concerned with the individuals weight or height development for some reasons, usually the school health nurse measures height or weight more frequently for a period to monitor the development, and if necessary the child is referred to a physician for further examination (79).

The data was collected from the records from the child’s health centres and school health records.

The collection of data from the records was done on three occasions, the first in grade 2 when the children were about 8 years, second occasion in grade 9 when the adolescents were about 16 years and third in grade 12 when they were about 19 years.

Approximately 10% of the children moved, changed school or dropped out of school, and therefore, it was not possible to obtain their health records from the school nurse. However, it was possible to attain most of the records since they were deposited in the local community archives after the individual left school. Total health records were collected from 3107 individuals out of 3,158 eligible individuals, resulting in 51 (1.6%) missing health records.

After excluding children with disorders or major impairment for growth, n=24, and after excluding children with fewer than two measurements, n=42 (19 boys and 23 girls). The total sample for the 1981 cohort was 3041 (50% boys) (79).

3.5.5 Method
The 1973 cohort and 1981 cohort were merged, giving a total or 6,572 individuals (51% boys, 49% girls).
BMI was calculated. A BMI reduction episode was defined as a consecutive multiple BMI reduction, measured from the first measure taken before the reduction to the last measurement before BMI increased again (5). The difference between the two measurements were calculated and reported in BMI %.

If a child had more than one episode of substantial BMI reduction, final height was tied height to the most substantial BMI reduction episode.

A substantial BMI reduction was considered as a reduction of ≥ 10%, this cut-off was chosen ad hoc.

The final height for a BMI reduction of ≥ 5%, > 5% < 10%, >10% <20% and ≥ 20%, were also calculated.

The rest of the sample, all with < 5% BMI reduction or no BMI reduction were categorized as no BMI reduction groups. Individuals with substantial BMI reduction were compared with individuals without BMI reduction.

The final height for boys was defined as height at 18 years (≥ 17.5–< 18.5 years) and 16 years (≥ 15.5–< 16.5 years) for girls. If an individual had any measurement after this age, the last measurement was used. Individuals with no information on BMI before the defined age, were classified as missing cases.

The duration of the BMI reduction episodes was stratified into four categories: less than one year, less than two years, less than three years and three years or more.

The starting points for all the BMI reductions episodes were ranged both according to the age interval in which they occurred and to the weight category the individual belonged to at the start. Based on monthly BMI cut-off values, each of the individuals with BMI reduction was categorized as either thin (BMI ≤ -1SD), normal weight (BMI > -1SD <+1SD), overweight (BMI ≥+1SD <+2SD) or obese (BMI ≥+2SD), according to the Swedish national growth reference from Werner (212). The age intervals used were 7–9 years, 10–12 years, 13–15 years and ≥16 years at the start of a BMI reduction episode.
3.6 Paper IV

3.6.1 Sample
The sample used in article IV was cohort 1973 and cohort 1981. The sample previously described in this thesis.

3.6.2 Data collection
Data collection for the 1973 cohort and 1981 cohort was previously described.

3.6.3 Method
Body weight was expressed as weight and relative weight. Weight and relative weight were weight for height kg/m (W/H), Body Mass index kg/m$^2$ (BMI) and Tri-Ponderal Mass Index kg/m$^3$ (TMI). Height on group level is also included in order to compare with dito weight development.

On group level, each year from 7-18 years, one height or weight measurement were used. If an individual had more than one measurement for the respective age, the height and weight measurement nearest to whole year were chosen.

On individual level, weight at age 7 years and 16 years ($\geq 15.5 < 16.5$) for girls and 18 ($\geq 17.5 < 18.5$) for boys were categorized by monthly values in the range of as $\leq -2$ SD, $-1$SD ($>-2 \leq -1$ SD), 0SD ($>-1 < +1$ SD), +1SD ($\geq +1 < +2$ SD), +2SD ($\geq +2 < +3$ SD) and $\geq +3$SD according to the growth reference from Werner (212).

For girls, the last weight measurement was set at 16 years because of substantial number of missing cases at age 18 years.

If an individual had more than one weight measurement within the respective age, the weight measurement nearest to the whole years was used.

3.6.4 1973 cohort and 1981 cohort, two longitudinal samples
The samples for paper III and IV were two high quality data samples, and in an international perspective quite unique considering that they both were nationally representative longitudinal samples with a very low number of missing cases.
3.7 Analysis
For paper I, III and IV, all calculations were performed for boys and girls separately, in paper III the descriptive statistics was performed for boys and girls separately.

For paper I–IV, P values were calculated using Student’s t-test and all P values were based on two-tailed comparisons and the level of significance set at 0.05.

For paper I–II data was entered into IBM SPSS Statistics, version 23 (SPSS Inc, Chicago, IL, USA). For paper III–IV, data was entered into IBM SPSS Statistics, version 24 (SPSS Inc, Chicago, IL, USA).

3.7.1 Paper I and II
In Paper I and II, the means and standard deviations (SD) for the children’s height, weight and BMI were calculated and presented for the respective age 7–9 years, in total and separately for boys and girls. Differences in height, and weight and the BMI between boys and girls were calculated using Student’s t-test and reported as P value.

In paper I, the median was also presented, because the sample was naturally skewed.

Effect sizes (Cohen’s d) were calculated and reported (Paper I). Cohen’s d measures the magnitude of difference between two means. The reference for Cohen’s d were; 0.2 small, 0.5 medium, 0.8 large and 1.3 very large (241).

The prevalence of thinness, normal weight, overweight, obesity and severe obesity were calculated using cross-tabulation. The results were presented as the number and percentage of individuals in the respective weight category. Differences between boys and girls were calculated using the Pearson’s chi-square test ($\chi^2$) (Paper I and II) and Fisher’s exact test (Paper I) for each age groups.

For consumption of breakfast, food items and beverage frequencies, the Pearson’s chi-square test ($\chi^2$) was performed to identify significant independent variables. The binary logistic regression model was used to establish association between all independent variables and the outcome variable overweight/obesity. Odds Ratios (OR) were computed to estimate the association between variables. In the adjusted model we adjusted for children’s sex, parent’s weight status and parent’s education level (Paper II).
3.7.2 Paper III
The final height was presented as means and SD. The differences in final height between individuals with and without BMI reduction were calculated using Student’s t-test, P value, mean difference and 95% confidence interval was presented.

3.7.3 Paper IV
The mean height, weight, and relative weight expressed as weight/height (W/H), BMI (kg/m\(^2\)) and Tri-Ponderal Mass Index (TMI, kg/m\(^3\)) on group level were calculated for each age from 7 to 18 for boys and girls, separately, in the 1981 cohort and 1973 cohort. The descriptive statistics were presented as means and SD for selected ages. The median was also presented, because the weight was naturally skewed.

On individual level, weights in kg at 7 and 16 years for girls and 18 years for boys were categorised monthly values for weight, according to the reference from Werner (212). Distribution of weight development expressed in SD from 7 to 16 years for girls, and 18 years for boys were calculated using cross-tabulation. The results were presented as numbers and percent-age.

3.8 Ethics
The first COSI data collection in 2008 was approved by the Regional Ethical Review Board for Stockholm (No. 2008/5:4). The corresponding regional board for Gothenburg stated that no approval by the committee was needed (No. 070–08). For the data collection of the COSI subsample in 2010, an active informed written consent was requested from the parents. Before both data collections, an oral consent was obtained from the child.

The data collection of Cohort 1973 and 1981 was approved by the Ethics Committee of the Örebro County Council (No.2000/09:27, 500:16 901/00).
4 Results

4.1 Paper I

The main findings were that the use of the different growth references showed considerable differences in prevalence of all degrees of thinness (grad 1, 2 and 3 combined) providing results from 7.5–16.9%, normal weight of 59.0–76.1% and overweight (including obesity/severe obesity) of 16.5–25.7% for boys, the corresponding values for girls were for thinness 6.9–13.7%, normal weight 63.4–75.0%, and overweight (including obesity/severe obesity) 18.2–25.2%.

Using the growth reference from WHO as the norm, the growth reference from IOTF gave the lowest prevalence of thinness (grad 1, 2 and 3 combined) and overweight (including obesity/severe obesity) for both boys and girls, while the growth reference from Werner rendered the highest prevalence of thinness (grad 1, 2 and 3 combined) for both boys and girls. For overweight (including obesity/severe obesity), the references from WHO yielded the highest prevalence for boys and Karlberg et al. had the highest prevalence for girls (Figure 1).
The descriptive statistics showed that boys age 7 and 8 years were significantly taller (p=<0.001) and heavier (p=0.0013 for 7 years, p=0.018 for 8 years) than girls, for 9-year-olds there was no significant difference in height and weight between boys and girls. Cohen’s d effect size for height was d=0.12–0.23 and for weight and relative weight d=0–0.13.
4.2 Paper II

A main finding was that the majority of children (95.4%) were reported by the parents to have breakfast every day. Among children not stated as having breakfast every day we found a significant association (p=0.001) with overweight (including obesity), where children not having breakfast every day was 1.9 times more likely to be overweight/obese than children having breakfast every day.

The parents reported that the majority of children had vegetables (84.7%) and fruit (83.9%) four days a week or more. For intake of both vegetables and fruit there was a significant gender difference (p <0.01), the boys were reported to have vegetables and fruit less than four days a week more frequently than girls. There was no significant association between the consumption frequency of vegetables and fruits and overweight/obesity.

The vast majority of children (≥ 95.5%) were reported to have snacks, sweets or chocolate, sweet bakery products and fast food (pizza, French fries, hamburgers, sausages or meat pies) less than four days a week. There was a significant gender difference (p=0.023), where the boys were reported to have a higher frequency of fast food items, four day a week or more than the girls.

For beverages, the majority of children were reported to have soft drinks containing sugar (94.0%), diet soft drinks (97.2%) and fruit juice (75.7%) less than four days a week. For skimmed/semi skimmed milk and whole fat milk, 84.8% and 82.9%, respectively, of the children were reported have these types of milk less than four days a week.

In the regression model, the risk of being overweight (including obese) was higher if the child was reported to not having breakfast every day (OR 1.9, CI 1.20–2.96), drink diet soft drinks (OR 2.6, CI 1.52–4.42) and drink skimmed/semi skimmed milk (OR 1.8, CI 1.37–2.36). When adjusting for gender, parenteral weight status and education level and area of living, this slightly attenuated the regression model. The risk of being overweight (including obese) was higher if one of the parents was overweight (including obese) (OR 1.9, CI 1.49–2.50) and if the parental education was below university level (OR 1.3, CI 1.01–1.61).
4.3 Paper III

On group level, there was no statistically significant difference in the final height between individuals with substantial BMI reduction episode of 10% or more and those without BMI reduction episodes. This results was independent of age and if the individuals were thin, normal weight, overweight or obese at the start of the BMI reduction episode.

Final heights for BMI reduction of $\geq 5\%$, $5\% < 10\%$, $10\% < 20\%$ and $\geq 20\%$ were also calculated and compared with those without BMI reduction, and on population level, there were no statistically significant differences in final height between the BMI reduction groups and those without.

When scrutinizing growth charts for individuals with substantial BMI reduction it was possible to identify cases where BMI reduction could have had an impact on final height.

4.4 Paper IV

Our main findings showed that the longitudinal patterns for height, weight and relative weight (W/H, BMI, TMI) for each age from 7–18 years on group level for boys and girls were almost the same when comparing individuals in the cohort 1981 and cohort 1973. However, for almost all ages, the height was slightly higher, and the weight and relative weight were higher for boys and girls in the 1981 cohort. The patterns for relative W/H and BMI are similar, and the pattern for TMI differed from those for W/H and BMI.

When comparing height, weight and relative weight W/H, BMI and TMI at the selected ages 7, 10, 13, 16 and 18 years on group level in the 1981 cohort with the 1973 cohort, the boys and girls in the 1981 cohort were significantly heavier (from p<0.001 to p= 0.026) for almost all the selected ages, with exception of boys age 7 years for weight, W/H and BMI, girls age 7 years for weight, 16 years for BMI and for 18 years for weight and relative weight.

For height, boys age 13 years were significantly (p=0.001) taller in the 1981 cohort, while the boys aged 7 years were significantly taller in the 1973 cohort (p=0.042), girls 13 and 16 years were significantly taller (p=0.003 and p=0.002, respectively) in the 1981 cohort.

On an individual level, three main longitudinal trajectories represented the weight development from 7 to 16 years for girls and 7 to 18 years for boys. The first trajectory was identified in the lower range of $\leq -1$ SD, where the majority of individuals moved up one SD channel or more from age 7 to 16 years for girls and 18 years for boys. The second trajectory was found...
among individuals in the mean range for weight (0SD as $>-1 < +1$ SD), where the majority of individuals ($\geq 78.8\%$) remained in the mean range from 7 to 16 years for girls and 18 years for boys. The third trajectory was identified among those in the upper range for weight of $\geq +1$SD. From the age 7 to 16 years for girls and 18 years for boys, the majority of individuals moved down to a lower SD channel, except for girls in the 1973 cohort in the $+1$SD channel, where the pattern was different, the majorities of girls remained in the same channel from 7 to 16 years. Out of 66 girls at 16 years 37.9% remained in the $+1$SD channel, 36.4% moved down a channel to mean range and 25.8% moved up to the channel of $+2$SD.

Even if the three patterns were mainly the same in the 1981 cohort and the 1973 cohort, there are some observable differences when comparing the 1981 cohort with the 1973 cohort. From 7 to 16 years for girls and 18 years for boys the percentage of individuals in the channels of $\geq +1$SD increased from 1973 to 1981. Also in the lower range for weight of $\leq -1$SD, the percentage of boys increased and from 1973 to 1981, for girls in the lowest range of $\leq -2$SD the percentages decreased and in the $+1$SD range the percentage increased from 1973 to 1981.
5 Discussion

The first main findings of the present thesis are as follows; when using four different growth references, two international (138,209) and two national (212,224) yielded considerable differences in prevalence of thinness, normal weight, overweight and obesity. Secondly, we found a significant association (p=0.001) with not having breakfast every day and overweight (including obesity), where children not having breakfast every day were 1.9 times more likely to be overweight/obese than children having breakfast every day. The majority of boys and girls had fruit and vegetables four days a week or more, sweets or sugar containing soft drinks less than four days a week. Thirdly, we found that a substantial BMI reduction of 10% or more did not have any impact on final height, neither did age or weight category at the time of weight loss. Fourthly, in a period of eight years the weight patterns for boys and girls on group level remain similar for almost all ages between 7 and 18 years, even if individuals born in 1981 were heavier than those born in 1973. When tracking weight development and changes in channels on individual level from age 7 to 16 years for girls and 18 years for boys, three main patterns were identified. In addition, the majority of individuals changed channel for z-score from 7 to 16 years for girls and 18 years for boys, except for individuals in the mean range where the majority stayed in the same channel.

5.1 Paper I. Different growth references showed considerable variations.

We found that using two international growth references, one from WHO (209) and the second from IOTF (138) and two widely used Swedish growth references, from Karlberg et al. (224) and the new Swedish national growth reference from Werner (212), yielded considerable variations in the prevalence of thinness, normal weight and overweight. Dependent of growth reference used, thinness varied from 7.5%-16.9% for boys, 6.9%-13.7% for girls. Normal weight varied from 59.0%-76.1% for boys and 63.4%-75.0% for girls, for overweight (including obesity and severe obesity) the prevalence varied from 16.5%-35.7% for boys and 18.2%-25.2% for girls. We also found differences according to gender.

The different results of prevalence of thinness, normal weight and different degrees of overweight are obviously a result of the different cut-off levels for the four growth references. When we scrutinized the respective
growth references, international (138,209) and the national growth references (212,224), it is obvious that there are substantial variations in regards to the background and the samples the respective growth references are based on.

In published papers on thinness and overweight/obesity among children and adolescents the most commonly used growth reference is the one from IOTF (138) or one of the previous versions (112,132) even if this is the growth reference deviating most compared with the growth references from WHO (209), Karlberg et al. (224) and Werner (212). Since the cut-off levels from IOTF reference are considerably different from the other growth references the use of this reference might result in misclassification of thin, overweight or obese children. Another well-known problems concerning the growth reference from IOTF is the problem with backtracking from 18 years to 2 years which is used (112,132).

To the best of our knowledge there are only two growth references that are based on longitudinal samples, one from Karlberg et al. (224) and the second from Werner (212), where the growth reference form Werner is the only one based on a nationally representative sample (212).

5.1.1 What is a growth reference supposed to express?
A growth reference should express what a normal or desirable distribution of height and weight looks like. In a descriptive approach, a growth reference describes how a child should grow in a defined location and at a specific period of time, a prescriptive approach can generate a reference describing how children should grow (205). The hallmark of a growth reference of good quality is transparency in regards to what the growth reference it based on and what it aims to express; descriptive or prescriptive values. Ideally, a growth reference should be based on a representative sample of the population, preferably longitudinal data in order to capture growth velocity especially in puberty (242), with no or few number of missing cases. Furthermore, a growth reference should be based on data from a population with a positive secular change for height, but no or minimal secular change for weight. With this in mind, considering the well documented positive secular change in height and weight development among children, adolescents and adults (3,57,79,243), to what degree the positive secular change has an effect on the growth reference are dependent on the birth year of the individuals included the samples.

When scrutinizing used growth references from WHO (209), IOTF (138) and CDC (211) and from the Scandinavian countries (212-216,224), Great-
Britain (217,230) and the Netherlands (100,223) the differences between the respective growth references became obvious. The samples were mainly cross-sectional (100,138,211,213,215), part cross-sectional- part longitudinal (214,216,230), mix longitudinal (208) or pooled (138,209,211). It also differed if they were based on nationally representative (212,223) or local samples (213,214,216,224,230), and if the growth references were are expressed in z-scores (209,212,222,224,231) or in percentiles (209,211,214,216,227,228,231). As pointed out, differences in the data the respective growth references are based on, makes comparison between studies and countries less meaningful. The picture became even more complex when trying to compare z-scores with percentiles. Due to the complex nature of the different growth references it was not possible to estimate to what degree the positive secular changes in overweight and obesity had any effect on the respective growth references.

5.2 Paper II. Consumption frequency of breakfast, and selected food items and beverages.

The majority of children was reported to have breakfast every day (95.4%). When comparing our findings with another group of 11, 13 and 15-year-old Swedish children (10), we found a higher frequency of breakfast consumption. A plausible explanation for this difference is the age of the children. In our study the children was 7–9 years while breakfast skipping is more prevalent among older children (10,11,174). Furthermore, the study on older children included questionnaire data completed by the children themselves (10,11,174), for younger children (11,174) as in our study the parents answered the questionnaire.

The majority of children were reported to have a rather favourable food and beverage intake pattern, for example to have fruit (84.7%) and vegetables (83.9%) more than four days a week. The daily recommendation of fruit and vegetables intake for children age 4-10 years is 400 g per day, with no reference to frequency intake (154). Foods like snacks (99.4%), sweets and chocolate (98.9%), sweet bakery products (95.5%), fast foods (98.3%) and sugar containing soft drinks (94.1%) were reported as less than four days a week.

Among 11-year-old children in ten European countries, about 40% and 60% of Swedish children reported having fruit and vegetables every day, respectively (244). For comparison, in our study, the parents reported a higher daily consumption of fruit among their children (63%), while the daily vegetable consumption in our study (55.0%) corresponded reasonably
well with the European study. We also found a significant (p<0.001) gender difference in fruit and vegetable consumption, with boys more frequently having fruit and vegetables less than four days a week. The same gender difference in consumption of fruit and vegetables was also observed in the above a study of Swedish 11-year-old children (244). Also, the majority of children 94% and 97.2% had sugar containing soft drinks and diet soft drinks, respectively less than four days a week. A low consumption frequency of soft drinks was also found in the Riksmaten study, children age 8 had sugar containing soft drinks 2.7 times per week and diet soft drinks 0.21 times a week (162).

5.2.1 Intake of breakfast, selected food and beverages in relation to overweight and obesity

We found a statistically significant association between not having breakfast every day and overweight and obesity, in fact children not having breakfast every day was 1.9 times more likely to be overweight and obese than those who had breakfast every day. Also in general, those not having breakfast every day had a lower consumption of fruit and vegetables, a higher intake of sugar containing soft drinks, sweet bakery products, sweets and chocolates and slightly more fast foods.

However, we did not find any association between sugar containing soft drinks and overweight and obesity. Other studies have previously identified a relationship between soft-drink consumption and overweight and obesity development among children (8,245). A recent review found a positive association between intake of sugar containing beverages and adiposity among children under the age of 5 years. For children under the age of 12 years a positive association was suggested with total adiposity and a strong association with central adiposity (158). Another systematic review on sugar sweetened beverages and weight gain in children and adults suggested that sugar sweetened beverages were positively associated and had an effect on obesity indices among children and adults (157).

A study of seven, nine and 13-year-old children from United Kingdom found that excess weight gain over a three year period was associated with consumption of food items such as potato crisps, French fries, sweets, desserts, full and low fat milk and sugar containing beverages (8).

We found that if one or both parents were overweight or obese and if the parents education level was below university level the children’s risk or be-
ing overweight (including obese) increased, this has previously been reported from the full Swedish COSI material from 2008 (238), and from other studies (87, 246-248).

Development of overweight and obesity among children is complex, however a substantial amount of literature indicated that reduced physical activity (4), increased intake of sugar and fat in foods (4) and sugar containing beverages (8, 157, 158, 245) and meal habits (10, 11, 174) have contributed to the overweight and obesity development observed among children and adolescents during the last decades (4, 158).

Meal patterns and meal practice also have also an influence on establishing food habits among children (9). An epidemiological study of children’s health and school meals in a northern part of Sweden (12) is one example of studies where other meals than breakfast have been explored.

The parents are important in creating environments for development of healthy or unhealthy food habits among the children. This can be done by introducing healthy food items such as vegetables and fruit and restricting food items like high dense food items or sweets (9), family sharing common meals and avoiding children eating alone in front of the television or computer (170, 171).

### 5.3 Paper III. Weight loss among Swedish children and adolescents

We found no evidence that substantial BMI reduction episodes between 7–19 years had any impact on final height on group level, independent of the length of the episode. Furthermore, we found no statistical evidence of the age or weight category at the time of the BMI reduction episode having any impact on final height (Tables 2 and 3).

To the best of our knowledge, there are no previous studies on BMI reduction episode and their impact on final height in an unselected population. Therefore it is not possible to compare our results with other studies, however, there are studies on subgroups such as BMI reduction among anorexia nervosa patients reporting no adult height deficit (249), while other studies suggest that a complete catch-up growth might not be achieved (250, 251) especially not among the most severely affected anorexia nervosa patients. There are some methodological challenges in studies on anorexia nervosa patients, such as small samples, heterogeneous populations, premorbid data, and the fact that information on final height often is missing (251). However, studies on growth among individuals with anorexia nervosa give us an indication of how different degrees of BMI reduction
during childhood and early adolescence can affect height growth and final height.

Another factor that might have contributed to our results was is that the living conditions were good for the Swedish children and adolescents in our sample. The individuals in our sample who might have had a decelerated height growth because of substantial BMI reduction episodes may well have benefitted from catch-up growth and thus more or less realised their biological height potential (49). Tanner (252) states that the most striking and perhaps most fundamental characteristic of human growth is its self-stabilizing and target seeking ability.

Even if, surprisingly, we did not find that a substantial weight loss episode of 10% or more had any impact on final height on group level, it was possible to identify cases where weight loss most likely could have an impact on final height. Within our sample there was at least one case that indicated a relation between reduction in BMI and final height. Also among the 56 primarily excluded individuals born in 1973 and 1981 with chronic diseases with major impairment for growth, a total of 5 children, 1 boy and 4 girls with information on final height with a BMI reduction of 10% or more after 6.5 years were identified. Mean height for the boy was 173.5 cm and for the four girls 145.5 cm, which for both genders is substantially lower than the reference population of about 180 cm for boys and 167 cm for girls (104).

Based on our findings, when investigating weight loss episodes this should be conducted on individual level, for example using case studies investigating several factors which in combination can cause a BMI reduction, and where the type and severity of the exposition decides the impact on final height.

5.4 Paper IV. Weight development in a longitudinal perspective

We have shown how the different measurements for weight and relative weight, W/H, BMI and TMI on group level, perform during growth within the two longitudinal samples. However, when using TMI as measurement the result was somewhat different. It was not possible to have any opinion of the plausible causes for the difference between the relative weight measures. However, Peterson (253) initiated a discussion about this in a recent paper, and we will follow this up in the future.

The positive secular change in weight and height among Swedish children and adolescents born in 1954–55 has been described by Westin-Lindgren. For these children, the mean weight were 66.5 kg for 18 year-old-boys and
54.3 kg for 16 year-old-girls (254). When compared with those born 1954-55, mean weight for the same ages in the 1973 cohort increased by 4.9 kg for boys and by 6.5 kg for girls.

On group level, the development of weight and relative weight showed that boys and girls born 1981 were heavier for almost all ages compared with those born in 1973. This increase in weight among boys and girls is caused by an on-going positive secular change for BMI, as previously described by Werner (111), and this secular change can also be seen for height, weight, W/H and TMI.

In a cross-sectional study of 7-9-year-old Swedish children, weight and relative weight for 7-year-old (age 7-7.99) children born in 2001, was 27.4 kg and 26.8 kg boys and girls respectively, BMI 16.3 for both boys and girls (255), which showed an increase in weight and relative weight compare with those born in 1981 where the corresponding data for 7.0 year olds were 25.0 kg for boys and 24.7 kg for girls, for BMI 16.0 for boys and girls (104).

When exploring weight development and changes in channels from 7 to 16 years for girls and 18 years for boys on an individual level, we identified three main trajectories for both genders in the two cohorts. Considering thoughts about canalization which apply to growth, height but also for weight (49), Tanner theorises that at 2-3-years of age a child will find and stabilize growth in its individual channel and remain there. Some will be pushed out of their path because of external factors such as starvation or illness, but there are regulative forces that tend to return growth into the original channel when the situation is normalized (29,49). Taking this into consideration, the majority of individuals should ideally remain in more or less the same channel from early age and onwards. However, a question worth considering is whether Tanner’s thoughts about canalization and its robustness back in 1978 (29) nowadays only applies to height and not for weight, because of the strong positive secular change for weight during at least the last five decades (79,243).

Looking at our results, the majority of individuals moved to a higher or lower SD channel for weight from age 7 to 16 years for girls and age 7 to 18 years for boys, except for individuals in the mean (0SD) channel and +1SD channel for girls born in 1973. Some of the changes and crossing of channels observed in this study can be interpreted as a result of the increasing frequency of overweight and obesity (111). In regards to the question of whether the change and crossing of channels to lower than -1SD could be
the result of an increasing numbers of BMI reductions episodes was previously described by Werner (5). As far as we know, there are no other studies exploring weight development for all weight categories expressed in SD on individual level comparing two national representative samples. There are, however, some longitudinal studies tracking overweight from childhood to adulthood (119,256,257). Our study showed that among children in the upper range for weight of ≥ +1SD at 7 years, the majorities of boys and girls moved down one channel for SD or more at the age of 18 years. Among girls the pattern alternates was mainly the same. We also found that in a period of eight years the percentage of girls increased in the upper range for weight of ≥ +1SD.

There is an earlier study, based on the same 1981 sample, where the predictors of overweight and obesity from birth to age 16 years for girls and 18 years for boys, were explored. Weight at 12 months was associated with overweight at 16 years for girls and 18 years for boys. Weight gain between 18 months and 4 years was the strongest risk factor for being overweight in late adolescence for both boys and girls. For children with low birth weight, less than 2500g, and high birthweight of more than 4500g, there was no association with being overweight or obese at 16 years for girls and 18 years for boys (122).
6 Methodological strengths and limitations

6.1 Paper I
The strength of COSI 2008 was that this was a dedicated growth study where trained staff used calibrated equipment and a standard protocol developed by the WHO Regional office for Europe (235). Because height and weight were measured, it could reduce the risk of information bias. Information bias is if the needed information about the subject is incorrect (258).

However, there could be a selection bias present if especially those children with overweight or in particular those with obesity were absent on the measurement day or parents opting out, even if the number of parents opting out was low (6.3%). Selection bias is a systematic error in a study that stems from the factors that influence study participation or procedure used to select subjects (258). There could also be a selection bias present because of refusal to participate from schools with large presence of immigrant children. Differential attrition and non-responses represent potential threats to the validity of the study finding. However, as described in a previous publication (113), we are quite confident that the relatively high rate of participation within the schools supports the notion that the participating schools provided representative data.

6.2 Paper II
As in paper 1, the strength of this study was that this was a dedicated study where trained staff used calibrated equipment and a standard protocol, which reduced the risk for information bias. Another strength of this study was that the findings were adjusted for a selection of potential confounders such as gender, parental weight, parental education and area of for living, which allowed for confidence in the results.

A food frequency questionnaires (FFQ) was used to gather information on intake frequency of 17 food items and beverages during a regular week. FFQs are suggested to be as good alternative for children age 12 years or older (159). The children included in this study were only 7–9 years, but the parents answered the questionnaire on behalf of the child or together with the child.

There are, however, several limitations which may have affected the results. The self-reported questionnaires’ filled out by the parents may have been affected by limitations related to memory or misinterpretation of ex-
posure. There was also a possibility of over reporting more favourable behaviours, or “socially desirable response” (166), for example breakfast habits and fruit and vegetable consumption, and to under-report less favourable behaviours such as consumption of sugar-containing soft drinks, cookies and sweets, resulting in skewed data.

It is a limitation that information on portion size or what food items the children had for breakfast or how many times per day they ate something. Bread and cereal products were not included in the questionnaires. It would also have been a strength for the study if other meals patterns than breakfast had been included.

6.3 Paper III
The strength of this study lies in the two nationally representative longitudinal data sets with few external missing cases, where almost all extremes were included and no selection bias existed in the samples, which made it possible to make a comparison over time as well as a comparison with other national surveys (79,104,106). Because of the high quality of the samples it was possible to use final height among the individuals with no BMI reduction episodes as a reference for final height for individuals with BMI reduction episodes. Another strength of this collected data, at least in theory, is that it is possible to replicate as long as records in child health care and school health are available on national level in local archives or in accessible databases.

A limitation was that this was not a dedicated study, which means that the data were not collected using a specified protocol. The use of specified protocols ensures that measurements are comparable with reference data, and facilitates the interpretation of results. A protocol can also, provides a basis for training of data collectors, and maximizes the reliability of the measurements (185). However, in this case, data were collected by trained health professionals such as child health care nurses and school nurses in their normal growth monitoring routine.

Another weakness could be the irregular data points for height and the absence of more frequent measurements, which means that the actual length of a BMI reduction episode could not be exactly determined. On a national level, it is difficult to evaluate the on-going positive secular change for height and weight, and this therefore needs to be further in more recent samples than those from this study, Swedish children born in 1973 and 1981.
6.4 Paper IV

As in paper III, the strength lies in the two nationally representative longitudinal data-sets with few external missing cases. This made it possible to track weight development in a longitudinal perspective on both group and individual level. It was also possible to control for robustness of the patterns for height, weight and relative weight for those in the cohort 1981 by using 1973 cohort as a reference for growth patterns and secular changes. We could control for internal missing cases among girls, where we suspected bias. We found that girls with missing information on weight at age 18 years, were significant heavier (p < 0.001) at age 16 years than those girls with information on weight at age 18 years.

It was also possible to track changes in weight channels expressed in SD for weight for age 7-16 years for girls and 7-18 years for boys. Because we chose only two data points for weight, one at age 7 and the other at age 16 years for girls and 18 years for boys, we do not know if the change in channels occurred in one sustained change or in alternating patterns. This needs to be further investigated, to better understand the growth pattern for all weight categories in a population, especially during puberty. The 1981 cohort and the 1973 cohort allows for investigating weight patterns for all ages such as age 10, 13 and 16 years, which will be done in a later paper.
7 Conclusion

7.1 Paper I
Using different growth references yielded substantially different results with regard to overweight and thinness categories. Comparing studies using different growth references on the prevalence of thinness and overweight is difficult, due to the way that growth references are constructed, as well as how the different degrees of thinness and overweight are calculated. The results are also influenced by methodological differences, such as population representative sampling, numbers of missing cases and whether height and weight were measured or reported by parents.

We might not need a national growth reference, but if we choose to have one, a good national growth reference should preferably be established as a part of the set-up of a new surveillance system within the established child and school health services. Even if an ideal situation would be to establish a common global definition of BMI for different degrees of thinness and overweight by age, in the absence of a common consensus, we recommend the use of international references combined with national ones. We can also argue that differences in growth related to foetal development, genetic or epigenetic circumstances limit the value of a global reference and the analysis of growth development might need to be adjusted according to ethnic background. When using data on overweight/obesity, it is important to understand which growth reference those stem from in order to compare groups or before/after interventions.

7.2 Paper II
The majority of the children in this study were reported to have a rather favourable food intake pattern. However, the children were more likely to be overweight or obese when reported to skip breakfast. This was also the case if the children consumed diet soft drinks and skimmed milk/semi-skimmed milk more than four days a week. The latter could be interpreted as an effect of being overweight/obese rather than a cause. The results of this study could be due to differences in parenting styles and should be followed by other studies further investigating the actual intake at breakfast and the amount of foods investigated, not only frequencies.
7.3 Paper III
We have found no statistical evidence to support that a substantial BMI reduction episode has an impact on final height. Neither did we find that a specific age or weight category at the time of a BMI reduction episode had any impact on final height. Further analyses of case studies are necessary in order to determine whether a substantial BMI reduction episode might have impact on final height on an individual level. Further studies are also needed among first generation immigrants, since those born outside of Sweden were not included in this study.

7.4 Paper IV
As a result of the positive secular change, boys and girls born in the 1981 cohort were heavier than individuals in the 1973 cohort on group level for almost all age groups. In spite of secular positive change for weight and relative weight, the weight development patterns remain about the same for those in the 1981 cohort and in the 1973 cohort, except when using the relative weight, TMI. We have identified three main weight development patterns that represent the description of weight development for boys and girls born in 1981, and these pattern were confirmed by comparing with the 1973 cohort. This description could be the basis for a discussion for a new international growth reference.
8 Contributions CAMS

This thesis is to be defined in the crossing between healthy growth, public health and meal science. The thesis is situated in the field of auxiology with a focus on somatic growth among children and adolescents, and deviant growth patterns as weight loss and obesity with some aspects of meal patterns and food intake.

Within all research projects an imperative question is what the outcome is supposed to be? For this thesis the overall outcome is health, preferably good health among children and adolescents. Food intake and meal patterns together with other factors are important for the health and well-being of children and adolescents. A situation of malnutrition as over or under nutrition (48) may lead to overweight/obesity or underweight/thinness.

Overweight and obesity among children and adolescents is associated with several health risk factors, further on childhood obesity is also an important predictor for adult obesity (4,118-120). Also underweight (low weight/age) or thinness (low BMI for age) or overweight and obesity among children and adolescents might cause health problems (71,124,126,148-150). The benefits by preventing development of underweight/thinness and overweight among children and adolescents or preventing overweight developing to obesity are substantial (4). Even if development of overweight and obesity is complex and multifactorial (4,238), an important part in the effort in preventing overweight and obesity is related to meal patterns, food and beverage intake (4,6-8).

This thesis is to be considered as a contribution to meal science by strengthening the knowledge of how children grow and about factors influencing growth. A knowledge that is important when developing healthy meals for children in different public spheres. Paper I contributes to the understanding and development of a critical view on how children are classified in weight categories as thin, normal weight, overweight or obese and what these classifications are based on. This contributes to a critical view of data on the number of overweight/obese children, when comparing data between groups or changes over time in relation to changes in meal content or meal environment.

Paper II contributes to the knowledge in regards to intake of breakfast and selected food and beverage intake in general and relation to overweight and obesity among 7–9-year-olds children. Even if we found that the majority of children were reported to have rather favourable breakfast habits and
food intake, overweight and obese children were reported to more frequently skipping breakfast. We also found a gender difference in food intake, the boys were reported to have a lower intake of fruit and vegetables, and higher intake of fast foods than the girls. In paper III we provided an understanding of how a substantial BMI reduction among Swedish children may influence is final height. Furthermore, in paper IV we provided a description of weight development patterns among Swedish children and adolescents in a longitudinal perspective on both group and individual level.

Meal Science is a truly multi-disciplinary area, which includes public health nutrition and aspects of public meal quality and service, but also other aspects such as meal aesthetics, environment and meal management/planning. It is important for professionals and scientists in meal science to have extended knowledge and competence in regards to different aspects of meals in the public sphere, such as meals in day care and school settings. Even if the main part of the family meals are eaten at home, except for mid-day meals (170), eating outside the home in commercial setting is becoming more frequent (171), also among families with children. This thesis can contribute to extended knowledge regarding the overweight/obesity development in Sweden and increase the understanding of the importance of likeable vegetables and other healthy options. This is vital information for those providing healthy meals for children and adolescents eaten outside of home in settings like day care centres, in schools or in restaurants.
9 Considerations for further research

Some potential future studies are listed here.

It would be interesting to investigate whether breastfeeding or supplement feeding has any bearing on final height. This would greatly increase our knowledge regarding height development in relation to infant feeding.

Further studies on the frequency and content of children’s breakfast are needed in order to disentangle the findings in this thesis.

Developing menus with likeable vegetables for restaurants, schools and day-care could be considered an important part of meal science, in order to increase the intake of vegetables among children. This should build on further investigation regarding frequency and portion sizes of vegetable intake among children of different age groups, as well as studies of current menus for children in restaurants, schools and day-care, including beverage options available.

Furthermore, studies on the age of introduction of vegetables, and how this affects the liking and consumption of vegetables among children and adolescents would greatly contribute with new knowledge to this important area.

To develop a new international growth reference with data based on positive secular change for height and minimal positive change for weight as well as new international growth references for selected subgroups, such as first generation immigrants.

Investigating weight loss on individual level and effect on final height and further investigating weight development and crossing of channels from 7–18 years by including measuring points at 10, 13 and 16 years would be very interesting.

It is also very tempting to revisit the “Barker hypothesis”; does a catch-up growth early in life have any impact on final height? Lastly, it would be interesting to investigate whether the timing of the adolescent growth spurt has any influence on final height.
10 Svensk sammanfattning

Bakgrund
Det övergripande syftet med denna avhandling är att undersöka barns och ungdomars kroppsslag tillväxt (längd och vikt) och beskriva avvikande tillväxtmönster som episoder av viktminskning och utveckling av fetma, samt faktorer som bidrar till denna utveckling.

Denna avhandling vill bidra med kunskap om mönster i barns tillväxt till de som arbetar inom hälso- och sjukvård. Avhandlingen betonar bl.a. vikten av hälsosamma måltider i daghem, skolor och restauranger samt måltider i hemmet.

Delmål
Att undersöka hur fyra olika tillväxtreferenser påverkar fördelningen av tunna, överviktiga och obesa individer bland barn i åldern 7–9 år (artikel I).

Att undersöka frekvensen av frukostförekomst och konsumtion av utvalda livsmedel och drycker mot nationella kostrekomendationer, samt andra studier av frukost och matintag. Dessutom att undersöka vilka sociodemografiska faktorer som kan påverka utvecklingen av övervikt och fetma (artikel II).

Att undersöka om en reduktion av BMI (kroppsmasseindex) på 10% eller mer under tillväxten påverkar den slutliga längden hos 7–19 år gamla svenska barn (artikel III).

Att beskriva mönster av viktutveckling bland svenska skolbarn i ett longitudinellt perspektiv, och om viktmönstren förblir desamma på grupp- och individnivå över en period av 8 år för barn födda 1973 respektive födda 1981 (artikel IV).

Metod och material
Denna avhandling innehåller fyra kvantitativa studier, två med tvärnittsdata och två utgående från två longitudinella födelsekohorter.

Den första studien med tvärnittsdata består av höjd- och viktdata från 4,518 svenska barn i åldern 7–9 år (artikel I).

Den andra studien med tvärnittsdata består av längd- och viktuppgifter från 2,620 svenska barn, samt information från ett frågeformulär besvaret av föräldrarna om barnens matvanor och intag av utvalda livsmedel och drycker (artikel II).
Den första av de två kohorterna (artikel III och IV) består av ett representativt urval individer med longitudinella data på längd och vikt från 7 år till 19 år för nästan alla barn (bortfall 4.6%) från hela Sverige, födda 1973.

Den andra kohorten består av ett representativt urval individer med longitudinella data på längd och vikt från födseln till 19 år för nästan alla barn (bortfall 1.6%) från hela Sverige födda 1981.

**Resultat**

Förekomsten av underviktiga barn i åldrarna 7–9 år varierade från 7.5% till 16.9% för pojkar och från 6.9% till 13.7% för flickor, förekomsten av övervikt (fett ingår) varierade från 16.5% till 25.7% för pojkar och 18.2–25.2% för flickor, beroende på om det var tillväxtreferens en som användes var från WHO, IOTF eller de två svenska från Karlberg et al och Werner. Det var också en skillnad mellan pojkar och flickor (artikel I).

Majoriteten av föräldrarna rapporterade att deras barn (95,4%) åt frukost varje dag. Flertalet barn åt frukost (84.7%) och grönsaker (83.9%) de flesta dagar i veckan.

Vidare rapporterades att endast 1.6% av barnen åt skräpmat och 6.0% drack läsk (med socker i) fyra dagar i veckan eller mer. Risken för övervikt eller fetma var högre bland de barn som inte åt frukost varje dag (oddskvot (OR) 1.9, och 95% konfidensintervall (CI) 1.20–2.96), drack sockerfri läsk (OR 2.6, 95% CI 1.52-4.42 ) och skummjölk / lätt mjölk (OR 1.8, 95% CI 1.37-2.36) fyra dagar i veckan eller oftare. Föräldrar som själva var överviktiga eller hade låg utbildningsnivå medförde en högre risk för att deras barn var överviktiga (artikel II).

På gruppnivå, fanns det ingen statistiskt signifikant skillnad i den slutliga längden mellan gruppen med BMI-minskning och de som inte haft någon episod med minskning i BMI. Det hade inte någon betydelse för slutlängden om pojkarna och flickorna var underviktiga, normalviktiga, överviktiga eller obesa eller hur gamla de var när BMI-minskningen inträffade. På individnivå kunde vi dock identifiera fall där en signifikant BMI-reduktion troligen påverkade slutlig längd (artikel III).

När vi jämförde kohorten de födda 1981 med de födda 1973, kunde vi observera att det longitudinella tillväxtmönstret för längd, vikt och relativ vikt för både pojkar och flickor var nästan identiskt, även om vikten och den relativa vikten i de flesta åldersgrupper var högre för de födda 1981. Vi observerade också att TMI-mönstret avvek liknande mot vikt/höjd och BMI.

Konklusioner:

Stora variationer i förekomsten av tunna, övervikt och fetma uppstod när vi använde fyra olika tillväxtreferenser, de två internationella och de två nationella. Det var också stora olikheter mellan pojkar och flickor (Artikel I).

För de flesta barn som deltog i studien rapporterade föräldrarna meddela ganska goda matvanor. Att inte äta frukost varje dag, att dricka sockerfri läsk och lättmjölk var mer utbrett bland överviktiga eller obesa barn. För att identifiera orsak och effekt krävs longitudinella studier (Artikel II).

Vi kunde inte konstatera att en betydande viktminskning under tillväxtåren i form av 10%-ig minskning av BMI hade någon inverkan på barns slutlängd i åldersgruppen 7–19 år (Artikel III).

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