DISSERTATIONES KINESIOLOGIAE UNIVERSITATIS TARTUENSIS
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CHANGES IN ANTHROPOMETRY, SOMATOTYPE AND BODY COMPOSITION DURING PUBERTY: A LONGITUDINAL STUDY

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ABBREVIATIONS

A1-A5 – axillary hair development
BIA – bioelectrical impedance analysis
BMC – bone mineral content
BMI – body mass index
B1-B5 – breast development
CT – computerized tomography scanning
CV – coefficient of variation
DXA – dual-energy X-ray absorptiometry
ECW – extracellular water
FFM – fat free mass
FM – fat mass
GH – growth hormone
G1-G5 – genitalia development
ICC – intraclass correlations
ICP-model – infancy, childhood and puberty model
ICW – intracellular water
ICPN-equation – a new ICP-model that incorporates paternal height
IGF – insulin-like growth factor
ISAK – International Society for the Advancement of Kinanthropometry
LH – luteinizing hormone
PAI – physical activity index
PHV – peak height velocity
PH1-PH5 – pubic hair development
RI – resistance index
SAT – subcutaneous adipose tissue
SAT-top – subcutaneous adipose tissue topography
SD – standard deviation
SEE – standard error of estimates
SH – follicle-stimulating hormone
TBW – total-body water
TE – technical error
TEM – tehnical error of measurement
UWW – underwater weighing
2C – two-component model
3C – three-component model
4C – four-component model
%FM – percentage fat mass

1. INTRODUCTION

Health in adulthood is closely related to the health of children. Understanding and quantifying the changes in different anthropometrical and body composition parameters during pubertal period would facilitate early recognition of children with aberrant changes and/or unusual levels of body composition. There is a tremendous number of studies where different anthropometrical and/or body composition parameters have been investigated in children using different measurement methods. Different growth patterns for height and body mass have been presented for the children of the U.S. (Siervogel *et al.,* 1991), the U.K. (Rona, 1998), France (Rolland-Cachera *et al.,* 1991), Netherlands (Rooks, 1989), the Czech Republic (Prokopec and Bellisele, 1993) and Hungary (Susanne and Bodszar, 1998). Various papers have presented data on the height and body mass of Estonian children as well (Aul, 1974, 1982; Silla and Teoste, 1989; Grünberg, 1995; Grünberg *et al.,* 1998). In contrast, specific anthropometrical measurements such as different skinfold, circumference, length, and breadth/length variables are not so well documented (Norton *et al.,* 1996). For a cross-sectional study, the International Society for the Advancement of Kinanthropometry (ISAK) recommends to investigate the following measurements: nine skinfolds, thirteen circumferences, eight lengths, eight breadths/ lengths (Norton *et al.,* 1996). To our knowledge, there have been no longitudinal studies that have used all these parameters to study the growth pattern in Estonian boys and girls throughout the pubertal period.

Adolescence, especially during pubertal development, is a sensitive and one of life's most critical periods with rapid changes in body size, shape, and composition, all of which are sexually dimorphic and difficult to assess using only simple anthropometrical parameters such as body height. During growth spurt boys typically grow 9 to 10 cm per year and girls slightly less — 8 cm per year (Tanner, 1962). The onset of puberty corresponds to a skeletal age of approximately 11 years in girls and 12 years in boys (Tanner *et al.,* 1975a). However, there is a significant interindividual variation in the timing and tempo of puberty, even among adolescents of the same gender (Roemmich and Rogel, 1995; Rolland-Cachera, 1995). Similarly with height spurt, puberty is also a time of significant body mass gain. Obesity is associated with sexual maturation in both boys and girls, but the association is different between genders. There is a positive association in girls but a negative one in boys (Wang, 2002).

Human body composition, particularly the content of the fat tissue and its distribution, has been extensively measured in healthy, diseased (Goran, 1997) and obese (Houtkooper *et al.,* 1996; Gray *et al.,* 1989) subjects of different ages (Baumgartner *et al.,* 1991). In order to assess body composition, a variety of non-invasive methods have been applied (Ellis, 2000; Lukaski, 1987). Most of them are based on a binary model (i.e., dividing human body into fat mass and fat-free mass). Unlike other methods, dual-energy X-ray absorptiometry (DXA)

measures three components of body composition — bone mineral content, fat tissue mass and lean tissue mass — as well as regional fat distribution (Slosman *et al.,* 1992). Recently, this method has been acknowledged as a criterion method for body composition studies in children and adults (Genton *et al.,* 2002; Sopher *et al.,* 2004). However, DXA has some disadvantages, namely that it is expensive, requires specific laboratory facilities and is not suitable for bedside investigation. In addition to this, different DXA machines may give varying results (Tothill and Hannan, 2000). Bioelectrical impedance analysis (BIA) is a commonly used method for determining body composition because it is non-invasive, reliable (Jackson *et al.,* 1988), inexpensive and portable method (Houtkooper *et al.,* 1989). However, BIA is highly dependent on the conductor's height and its impedance (Brodie *et al.,* 1998; Hills *et al.,* 2001). The influence of different specific anthropometric variables on the body impedance in children during puberty has been poorly studied. Variation in hydration of fat-free mass (FFM) is relatively high in children (Hewitt *et al.,* 1993).

2. REVIEW OF LITERATURE

2.1. Factors influencing the growth of children

Growth may be defined as a quantitative increase in size or mass. Maturation is related with the process and the state of reaching functional capacity in terms of biological, behavioral, and cognitive capacities (Malina and Bouchard, 1991). Growth refers to measurable changes in body size, physique, and body composition — whereas biological maturation refers to progress toward the mature state. Biological maturation varies not only among body systems but also in the timing of progress (Beunen and Malina, 1996).

Infancy, childhood, puberty — growth model

The model splits growth into three additive and partly superimposed components, appropriately named infancy, childhood and puberty (ICP) model (Karlberg, 1987). A key feature of this model, compared with others, is that the components correspond with known features of the endocrinological regulation of growth and can be considered in isolation from one another (Karlberg, 1987).

The **infacy stage** occupies the first three years of the human post-natal life. The rate of decrease in velocity, or deceleration during that period is very steep, which makes infancy the life stage of most rapidly changing rate of growth (Bogin, 1999). The infant's curve of growth is a continuation of the fetal pattern, in which the rate of growth in length actually reaches a peak in the second trimester and then begins a deceleration that lasts until childhood (Bogin, 1999). Habicht *et al.* (1974) and Van Loon *et al.* (1986) have demonstrated that the growth of normal birth weight infants is remarkably similar during the first six months of life. After six months of age, when breast milk alone no longer meets the nutritional demands of the growing infant and other specially prepared infant foods must be supplemented, infants from the developed nations or higher socioeconomic classes may become significantly larger than their less privileged age-mates from poorer environments (Habicht *et al.,* 1974; Van Loon *et al.,* 1986).

The **childhood stage** follows infancy, encompassing the ages of about three to seven years (Bogin, 1999). Childhood may be defined by its own growth pattern, feeding behavior, motor development and cognitive maturation (Bogin, 1999). At the beginning of childhood, the rapid deceleration in the growth rate that characterizes infancy ends and the growth rate levels off at about five centimeters per year (Bogin, 1999). Johnston (1986) has examined the physical growth changes in height, body mass and body composition that takes place during the childhood years. He pointed out that one of the most important features of human growth at this time is its predictability, both within individuals and between populations. The end of childhood is also marked by a small increase in the velocity depicted, called the growth spurt (Tanner, 1947; Butler *et al.,* 1990).

The **juvenile stage** is defined as the prepubertal stage where individuals are no longer dependent on their mothers (parents) for survival (Pereira and Altman, 1985). The juvenile period is often accompanied by a pronounced, but short-lived decrease in growth rate (Bogin, 1999). The primary hormones necessary for growth are growth hormone (GH) and thyroid hormone. GH facilitates the synthesis of protein, prevents the formation of fat and carbohydrate, and is necessary for the proliferation of cartilage cells at the epiphyseal plate permitting linear growth. Thyroid hormone is necessary for normal growth and development of the central nervous system and works together with GH to facilitate cartilage and bone formation. In addition to this, insulin has an important role in the regulation of growth through the supply of metabolic substrate to cells and interaction with other growth factors to influence fetal growth. During childhood, boys and girls have similar GH secretion patterns with a marked day-night rhythm. Insulin-like growth factor (IGF)-1 has an important role in muscle tissue growth through the stimulation of glycogen accumulation and the transfer of amino acids into cells for protein synthesis. Through the stimulation of cartilage growth and the formation of collagen, it also facilitates the growth of connective tissue, cartilage and bone. In order to grow, children need adequate nutrition, it part through its effects on the GH/IGF-1 axis. Proper nutrition as well as insulin are necessary for GH-stimulated IGF-1 production (Thissen *et al.,* 1994).

The **adolescence stage** begins with puberty, or more technically with gonadarche, which is the reinitiation of activity of the hypothalamic-pituitary-gonadal system of hormone production (Bogin, 1999). Hormones exert independent effects during puberty, but the interaction of gonadal and adrenal steroid hormones with GH becomes essential for the normal adolescent growth spurt and sexual maturation (Rogol *et al.,* 2002).

Hormonal control of growth continues to depend mostly on the thyroid hormones and the GH/IGF-1 axis. With the beginning of puberty, the hormonal regulation of growth becomes more and more complex. For normal growth, sufficient levels of thyroid hormone and cortisol are still needed, but gonadal steroid hormones obtain a major role now. Bone mineralisation during puberty is also influenced by adequate calcium intake, physical activity and ethnic background (Rogol *et al.,* 2002).

Puberty is preceded by an increase in the amplitude of luteinizing hormone (LH) and follicle-stimulating hormone (SH) secretion, which can be detected even before the external signs of puberty. A rise in the level of these hormones facilitates the development of secondary sex characteristics and the changes in body composition that are noted in puberty. By promoting epiphyseal fusion through direct effects on the growth plate, gonadal steroid hormones enhance bone mineral accrual and affect adult height as well (Attie *et al.,* 1990). During development in puberty, the interactions between GH and the sex steroid hormones are remarkable and extensive. Various studies with adolescent boys have shown that the rising level of testosterone during puberty plays a crucial role in increasing spontaneous GH secretion and production (Martha *et al.,* 1992; Rose

et al., 1989). In contrast, estrogen modulates GH secretory activity in a completely different manner; low doses of estrogen stimulate IGF-1 production through improved GH secretion, whereas higher doses inhibit IGF-1 production at the hepatic level (Ho *et al.,* 1987). Estrogens are also responsible for skeletal maturation and ultimate fusion of epiphyseal plates (Rogol *et al.,* 2002).

The timing of puberty, i.e. the onset of puberty, can be described in various ways; for example, it can be described as the stages of secondary sexual characteristics, age of menarche in females or age of voice breaking in males, changes in sex hormone levels or height velocity (Tanner, 1962; Tanner, 1978). The age at which peak height velocity (PHV) (see Fig 1., 2.) occurs is usually within 2 years after the onset of puberty (Karlberg and Wikland, 1995). According to a study by Taranger *et al.* (1976), the statistical distribution of the timing of PHV in adolescents was approximately normal, with a mean of 11.6 years in girls and 13.5 years in boys; a standard deviation of close to 1 year for both sexes. There has been a secular trend towards a decrease in the age of PHV, with falls of 0.4 years for females and 0.5 years for males born in 1974 compared with children born in 1956 (Taranger *et al.,* 1976).

It has been found that the ICP-model and the ICPN-equation (a new ICP-model that incorporates paternal height) may predict the adult height of pubertal boys more accurately than the methods that use bone age (Limony *et al.,* 1993).

One hypothesis is that growth during childhood and juvenile stages is more sensitive to environmental factors, and growth during adolescence is determined more by genetic factors (Kaur and Singh, 1981). Growth at all stages of development is controlled by the interaction of genetic and environmental factors (Malina and Bouchard, 1991). Accordingly, it is more accurate to state that this hypothesis divides the relative weight of the contribution of genes and environment to this interaction differently during the pre-adolescent and adolescent stages of growth. The other hypothesis is that girls are better "buffered" against environmental determinants of growth, especially negative influences such as undernutrition and disease, than boys (Stinson, 1985).

2.1.1. Biological maturation (age)

Chronological age is a poor marker of biological maturity in children. There are considerable varieties of physical characteristics among children of the same chronological age (Beunen and Malina, 1996; Veldre and Jürimäe, 2004). The process of maturing has two components: timing (e.g., age when menarche is attained, age at the beginning of breast development, age at the appearance of pubic hair, or age at maximum growth during the adolescent growth spurt) and tempo (i.e., how quickly or slowly an individual passes from the initial stages of sexual maturation to the mature state) (Baxter-Jones *et al.,* 2005). The first critical period of biological maturation in regard to motor function is in infancy or early childhood, the second critical period appears at the age of seven to nine,

and the third critical period is during puberty (Viru *et al.,* 1999). The biological maturation of children can be estimated by different techniques. The most common systems include: 1) skeletal maturation or bone age (Faulkner, 1996; Malina and Bouchard, 1991; Malina and Beunen, 1996); 2) sexual maturation (Faulkner, 1996; Malina and Beunen, 1996); and/or 3) somatic (physique) maturation (Faulkner, 1996; Malina and Beunen, 1996; Rowland, 1996).

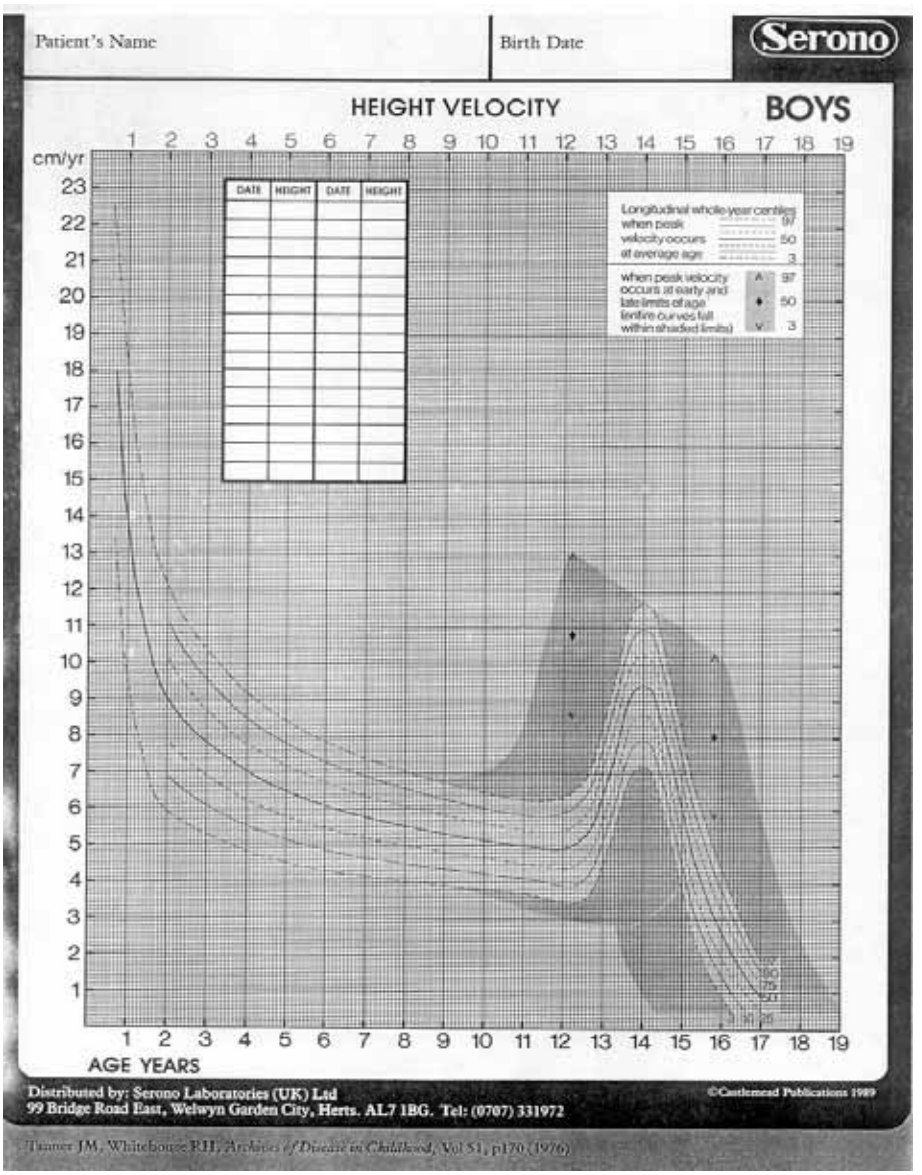

Figure 1. Mean height velocities in boys 1 to 17 years of age (Tanner and Davies, 1985).

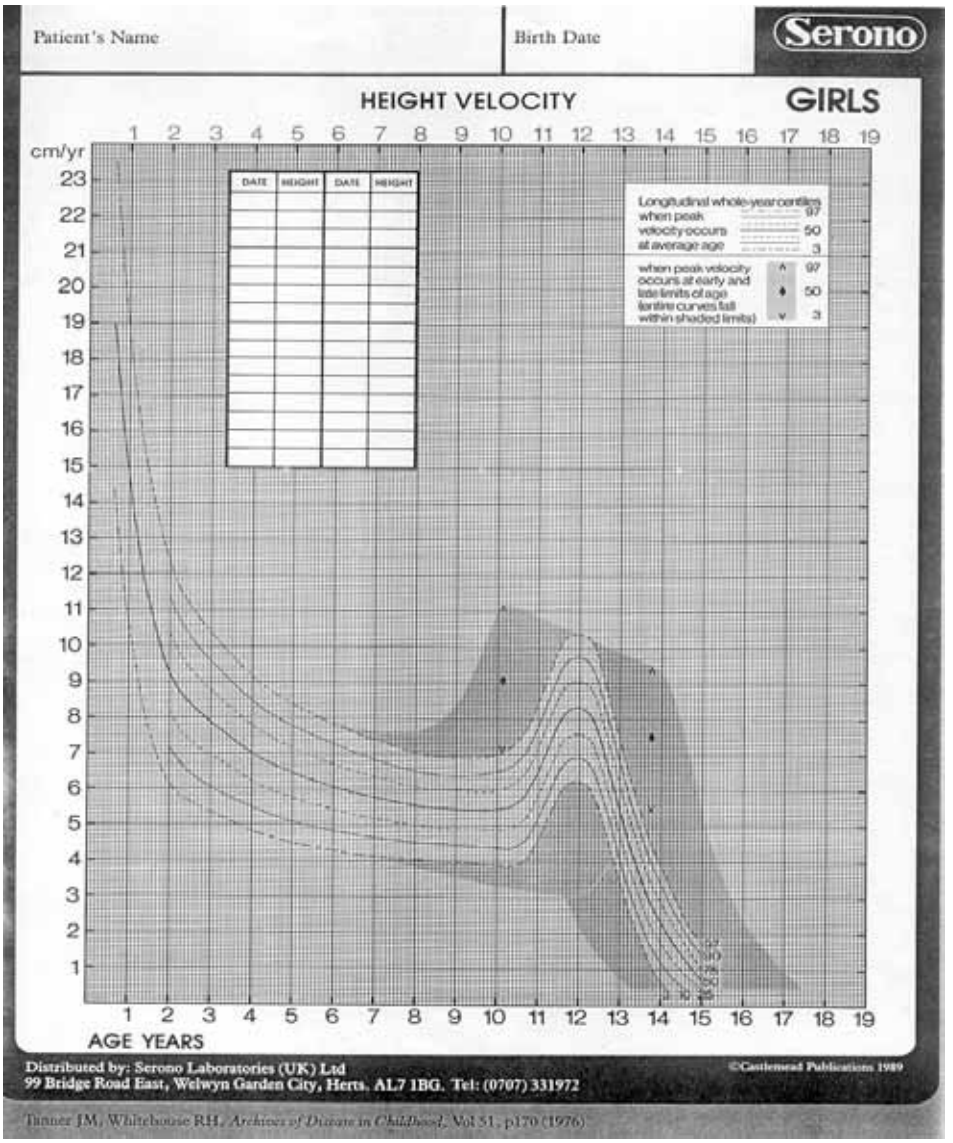

Figure 2. Mean height velocities in girls 1 to 15 years of age (Tanner and Davies, 1985).

Skeletal maturity (bone age) is perhaps the best and most commonly used indicator for assessing the biological age or maturity status in children (Tanner, 1962). The assessment of skeletal age is based on the fact that a more mature child has more bone development and less cartilage than a less advanced child (Rowland, 1996). The X-ray of the left hand is most often used for determining

the bone age. Three methods are available: 1) the Greulich-Pyle method (1959) — based on the original work of Todd (1937) (and is sometimes called the atlas method), is assessed by comparing a radiograph to a series of standard radiographs photographically reproduced in the atlas. The bone age of the measured subject is the chronological age assigned to the standard most closely approximating the radiograph; 2) Tanner-Whitehouse method (1975, 1983) — this system requires 20 bones of the hand and wrist to be assessed individually and a score to be assigned to each. The summation of these scores results in a bone maturity score, which is equivalent to a particular bone age; and 3) Fels method (Roche *et al.,* 1988) — this method is used for assessing skeletal maturity of the hand-wrist. Maturity indicators for each bone of the hand and wrist have been defined and their presence verified. The reliability of each indicator is validated on a set of radiographs. Different maturity indicators are involved in assessments at different chronological ages. The changes that each bone of the hand and wrist go through from initial formation to epiphyseal union or adult morphology are the same. The three aforementioned methods use these changes in a somewhat different manner to obtain an assessment of skeletal maturity at a given point in time. The rate at which skeletal maturation progresses, varies among individuals and perhaps among populations as well. The assessment of skeletal age is considered the best maturational index. However, it is expensive, requires special equipment and interpretation, and incurs radiation safety issues (Baxter-Jones *et al.,* 2005).

Sexual maturation is related to the overall physiological maturation and can be used in estimating biological maturation. The most commonly used criteria are described as the Tanner Scale or the Tanner Staging Technique (Tanner, 1962), in which the assessment of sexual maturity is based on secondary sex characteristics. Secondary sex characteristics, stages for pubic hair, breast and genital maturation, are ordinarily categorized in five or six developmental stages for each characteristic. They usually describe stages B1-B5 (breast development) in girls, stages G1-G5 (genitalia development) in boys, stages PH1-PH5 (pubic hair development) in both sexes and stages A1-A5 (axillary hair development) in both sexes (Tanner, 1962). For example, the beginning of puberty in girls starts with the budding or initial elevation of the breasts (B2) which is most often the first overt sign of sexual maturation in girls and stage 1 for pubic hair (P1-pubic hair has not yet appeared). In boys, the beginning of puberty starts with the initial enlargement of the testes (G2) and stage 1 for pubic hair (PH1).

Rating of the stages of sexual maturation ordinarily made by visual observation at clinical examination may have limitations because the method requires invasion of the individual's privacy. In order to address these problems, techniques based on self-assessment have been developed (from photographs and drawings), and it has been demonstrated that children can rate their own sexual development accurately and reliably (Duke *et al.,* 1980; Sclosserberger *et*

al., 1992; Williams *et al.,* 2003). However, there are still concerns that youths may overestimate early stages and underestimate later stages of sexual development (Cameron, 2002).

Assessing maturity by using different body size measurements is not possible because body size by itself is not an indicator of maturity, though somatic maturation is visually the most obvious expression of biological maturation of the child (Rowland, 1996). However, the use of physique measurements as indicators of maturity status requires longitudinal data (Malina and Beunen, 1996; Rowland, 1996). If longitudinal data that span adolescence are available, specifically for height, the inflection in the growth curve that marks the adolescent growth spurt can be used to derive indicators of maturity such as age at the onset of growth spurt and age at maximum rate of growth during the spurt (Malina and Beunen, 1996).

In conclusion, for the measurement of biological maturation, it is recommended to use several simple methods, and relatively complicated and expensive methods (e.g., DXA), and it is advisable to use more than one parameter. The most widely used method for assessing sexual maturity is based on the assessment of secondary sex characteristics (Tanner, 1962).

2.1.2. Physical activity

Physical activity can be defined as any body movement produced by skeletal muscles, which results in energy expenditure above the resting level (Caspersen *et al.,* 1985). Physical activity has mechanical, physiological, and behavioral components (Malina *et al.,* 2004). It is often assumed that regular physical activity is important for normal body growth and maturation. Studies that have continued for almost a century (Malina *et al.,* 2004) have claimed that regular physical activity, including training for sport, has a stimulating effect on growth and maturity.

In order to carry physically active behavior into adulthood, it seems only reasonable that children should be physically active during childhood, since regular physical activity is associated with health status in adults (Yang *et al.,* 1999; Trudeau *et al.,* 2004). Several studies (Paffenbarger *et al.,* 1984; Telama *et al.,* 1997) provide evidence that childhood physical activity habits may determine adult levels of physical activity. Children have an inherent biological need to be physically active although the activity is spasmodic (Rowland, 1998). Health concerns such as adiposity, psychological functioning, immune status, and risk of musculoskeletal injury may be influenced by physical activity in children (Sallis and Patrick, 1994). In order to minimize the risk of adult chronic lifestyle-related diseases (Astrand, 1994), regular physical activity in childhood has an important role in a child's health (Riddoch and Boreham, 1995; Sallis and Patrick, 1994).

According to a recent study with 9- and 15-year old European children, the physical activity level of boys tends to be higher than girls, and there is a marked reduction in activity over the adolescent years (Riddoch *et al.,* 2004). Adolescents engage in group sports such as dancing lessons more often than preadolescents, whereas adolescent children do not spend as much time running and playing outside than do the prepubertal children (Malina and Beunen, 1996). A study with children aged 6 to 18 has shown that through these years, males were more active than females and the frequency of physical activity declined with the advancement of adolescence (Sallis *et al.,* 1995). This study pointed out that the decline in physical activity was greater in girls, amounting to 3–7% per year, compared to 2–3% per year in boys (Sallis *et al.,* 1995).

Health benefits of regular physical activity in children are: improved body composition, improved cardiorespiratory fitness, improved psychological health, improved immune status, improved agility and functional independence (Jürimäe and Jürimäe, 2001). On the contrary, connections between insufficient physical activity, obesity, and high blood pressure have been found (Boreham *et al.,* 1997; Maffeis *et al.,* 1997).

2.1.2.1. Assessment of physical activity

The measurement and description of physical activity should probably consider the following aspects: 1) type and purpose of physical activity (e.g., recreational or obligatory, aerobic or anaerobic, occupational); 2) intensity; 3) efficiency; 4) duration (i.e., time); 5) frequency (i.e., times per week); and 6) specific energy cost of the activity performed (Harro, 1997; Kemper *et al.,* 1997). It should be noted that physical activity and exercise are not synonymous. Exercise usually refers to structured activities that are performed in order to improve physical fitness and well-being. This distinction is particularly important in children (Goran, 1998).

The following methods have been proposed for assessing physical activity in children (Harro, 1997; Harro and Riddoch, 2000; Jürimäe and Jürimäe, 2001; Melanson and Freedson, 1996; Riddoch *et al.,* 2004):

- **questionnaires (interview, diary)** are commonly used methods for estimating physical activity and energy expenditure, and are directed to the child, parent, or teacher (e.g., Telama and Yang, 2000) used a short self-report questionnaire that consisted of items concerning the frequency and intensity of physical activity, ways of spending leisure time, and participation in organized sports);
- **direct observation,** which lies in monitoring and/or videotaping children in their normal environments;
- **activity recall or record** is often a subjective method as time is difficult to recall and children cannot provide accurate information about their activities;

- **mechanical motor sensors (pedometer, accelerometer)** are less costly and time consuming and also more sensitive to variation in physical activity than many other methods;
- **heart rate monitoring** is used as a valid and practical indicator of physical activity in children;
- **indirect calorimetry** is an accurate technique for assessing daily physical activity and determines energy expenditure from oxygen consumption and carbon dioxide production; and
- **doubly labelled water** is used for the validation of other less direct measurements of physical activity.

The utmost shortcoming of all techniques is that the validity, reliability, and objectivity of many of these methods are not yet well determined. The problem lies in that there is no universally accepted criterion method for the validation of measures of physical activity and caloric expenditure (Melanson and Freedson, 1996; Rowland *et al.,* 1997). When the number of studied children is relatively high, different questionnaires should be used (Jürimäe and Jürimäe, 2001).

2.1.2.2. Physical activity and anthropometrical parameters

Regular physical activity has no obvious effect on the attained height and speed of growth in height (Beunen *et al.,* 1992; Saris *et al.,* 1986). However, regular physical activity does not have a negative effect on growth in height, either. Differences in the body mass of active and inactive boys and girls are generally small and insignificant (Beunen *et al.,* 1992; Saris *et al.,* 1986). Some data suggest that regular physical activity is associated with a decrease in obesity and an increase in fat-free mass (Malina *et al.,* 2004). The partitioning effect of training of FFM from the expected changes associated with growth and maturation is difficult, especially during adolescence. Both sexes have a significant adolescent growth spurt in FFM; in males even more so than in females (Malina *et al.,* 2004). The question of sex differences in the responses of FFM and fat mass (FM) to regular physical activity programs during growth needs to be studied further. In studies of children and youth, adipose tissue is often measured subcutaneously in the form of skinfold thicknesses. Although the cross-sectional comparisons of active and less active children and adolescents indicate thinner skinfolds in the former, the longitudinal data for active and inactive boys and girls followed from 6 to 12 years of age (Saris *et al.,* 1986). The differences that lie in the skinfold thicknesses fit well within the range of technical error associated with the measurement of skinfolds (Malina, 1995a, b).

2.2. Anthropometric changes during puberty

The purpose of different anthropometrical measurements is to assess and monitor the growth of children. Growth in height and body mass has extensively been used as an indicator of the health and nutritional status of children (Parizkova, 1996; Rolland-Cachera, 1995; Tillmann *et al.,* 2002). In addition to measuring body height and body mass, body mass index (BMI) is often calculated for children, in which body mass (kg) will be divided with body height $(m)^2$. BMI curves of Estonian children are presented as well (Grünberg *et al.,* 1998). More detailed growth data, such as different lengths, breaths, circumferences and skinfold thicknesses indices during puberty are, however, not well documented (Norton *et al.,* 1996). It has to be considered that body mass and skinfold thicknesses are more dependent on the environment, while different length and breath variables of the skeleton are more genetically determined (Carter *et al.,* 1997; Norton *et al.,* 1996). However, the growth pattern of a child is the result of a continuous interaction between the child's genes and environment.

Different anthropometric measurements have been used in order to study growth in children:

1. Direct measurement (e.g., skinfolds, circumferences, breadths, diameters) (Rolland-Cachera, 1995);
2. Indices (e.g., body mass index) (Susanne and Bodszar, 1998);
3. Areas (e.g., upper arm muscle area based on arm skinfolds and arm circumference) (Gutin *et al.,* 1996);
4. Regression equations relating body density to anthropometric measurements for a reference population (Parizkova, 1996).

Before puberty the variations in the anthropometrical parameters of boys and girls are relatively small, girls regularly have the more adipose tissue than boys (Jürimäe and Jürimäe, 2001; Siervogel *et al.,* 1991). Puberty starts earlier in girls than boys and is expressed as a quick increase in different anthropometrical parameters. Growth of children in height is especially quick in the first year and can be up to 30 cm in year (Roemmich and Rogel, 1995; Rolland-Cachera, 1995). Figures 1 and 2 present the mean height velocities of boys and girls (Tanner and Davies, 1985). Two-year old children can grow 9 cm per year and five-year old children 7 cm per year (Roemmich and Rogel, 1995; Rolland-Cachera, 1995). In the prepubertal period, the mean growth in height is about 5.5 cm per year (Roemmich and Rogel, 1995; Rolland-Cachera, 1995).

In connection with the beginning of puberty, the growth in height begins to accelerate approximately at the age of 10 in girls. The growth in height is faster in 12-year old girls, making an annual average of 10.5 cm. In boys, the growth in height does not accelerate before the age of 12 and the peak height growth is at the age of 14 — exceeding then 12 cm a year (Roemmich and Rogel, 1995; Rolland-Cachera, 1995). The body mass growth of prepubertal children

decreases linearly with the increase of age: about 10 kg per year in the first two years of life and later up to 3 kg per year. In conjunction with puberty the growth in body mass of 13-year old girls can be up to 8.5 kg per year and in 14-year old boys 9.5 kg per year (Roemmich and Rogel, 1995; Rolland-Cachera, 1995).

Not all parts of the body experience the adolescent growth spurt at the same time (Satake *et al.,* 1994; Bogin, 1999). For example, different regions of the skeleton, reach the peak rate of growth during adolescence at different ages (Satake *et al.,* 1994). Muscle mass in boys also undergoes a spurt at adolescence, and it is relatively greater than the spurt for growth in height. After the peak of the skeletal spurt, the rate of bone growth declines more steeply than the rate of muscle growth, meaning that adolescent boys continue to increase their muscle mass faster than they grow in height (Bogin, 1999). When expressed another way, the average healthy boy reaches 91 percent of his adult height typically at about the age of 14, which is the age of peak height velocity during adolescence (Buckler, 1990). However, the same average boy achieves only 72 percent of his total muscle mass at the age of peak height velocity and it takes about four more years to reach 91 percent of his adult value (Buckler, 1990).

There is little difference between the average height of boys and girls until adolescence, after which boys are typically taller than girls (Roemmich and Rogel, 1995; Rolland-Cachera, 1995). Girls usually begin their adolescence growth spurt about two years earlier than boys, which means that average girls are taller than their male age-mates for a couple of years. Boys have greater average muscle mass at all ages, though the differences become absolutely greater, and biologically important, at adolescence (Roemmich and Rogel, 1995; Rolland-Cachera, 1995).

The trends for fat distribution during growth are largely based on cross-sectional studies and there is limited data about adolescents. They only reflect the trends of groups and may not be valid in case of individuals. Changes in the distribution of subcutaneous fat during adolescence are connected with the timing of the growth spurt and sexual maturity. In a principal component analysis, the trunk-extremity principal component increases with stage of sexual maturation in males, but not in females (Baumgartner *et al.,* 1986). This trend reflects the simultaneous decrease in extremity skinfold thicknesses and increase in trunk skinfold thicknesses of males during sexual maturation. When specific skinfolds are related to the timing of the growth spurt, differential changes and timing of the changes are also evident. In a large study of Belgian boys (Beunen *et al.,* 1988), for example, subscapular and suprailiac skinfolds, and triceps and calf skinfolds differ in their timing of PHV. Estimated velocities for the subscapular skinfold remain positive throughout the growth spurt and do not vary relative to PHV. However, velocities of the suprailiac skinfold peak about one year before PHV and then decline around the time of PHV. Thus, upper- and lower-trunk skinfolds obviously behave differently during the adolescent growth spurt.

Conversely, girls differ only in overall fatness and not in the distribution of subcutaneous fat (Malina *et al.,* 1988). They tend to have more subcutaneous fat at all ages, and the difference between the fatness of boys and girls increases during adolescence (Roemmich and Rogel, 1995; Rolland-Cachera, 1995). On average, girls add FM continuously from age eight to 18, with a slowing or possible loss of fat at the time of the adolescent growth spurt (Malina and Bouchard, 1991). Most boys experience absolute loss of total FM during adolescence, and may have no more fat at age 18 than they had at age six (Malina and Bouchard, 1991). The adolescent spurt in muscle mass in boys is usually accompanied by an increase in bone density, an increase in cardio-pulmonary function, larger blood volume, and greater density of red blood cells. Increases in each of these also occur in girls, but at levels relatively and absolutely lower than for boys (Malina and Bouchard, 1991).

In conclusion, the shape of the adolescent growth spurt is not symmetrical. The rise to peak height velocity is relatively slower than the fall after the peak. The size of the spurt is usually greater in boys than in girls, although there is much individual and population variation in this.

2.3. Changes in somatotype components during puberty

Somatotyping, one of the most useful indirect techniques of evaluating physique characteristics, is a quantification of the present shape and composition of the human body (Carter *et al.,* 1997). The most common somatotyping method used is the Heath-Carter anthropometric somatotype method (Heath and Carter, 1967; Carter and Heath, 1990). This method divides the human body into the following components:

1. **Endomorphy** refers to the relative fat of subjects. This component characterizes the amount of subcutaneous fat on a continuum from the lowest to the highest values;
2. **Mesomorphy** refers to the relative musculoskeletal robustness in relation to stature. This component appraises skeletal muscle development on a continuum from the lower to the highest values; and
3. **Ectomorphy** refers to the relative linearity and fragility of the body. This component expresses the predominance of body surface area over body mass.

The combined rating of each component describes an individual's somatotype. If one of the components is dominant, the individual's somatotype is described by that component (Carter and Heath, 1990). According to Carter and Heath (1990), the somatotype is an overview of the total physique, which is independent of body size (Heath and Carter 1967; Carter *et al.,* 1997). In different growth studies, evaluation of the somatotype is particularly important in providing estimates of changes over time associated with children's growth and

development (Carter *et al.,* 1997). However, somatotype components have a genetic background in children (Peeters *et al.,* 2003) and the stability is high (Claessens *et al.,* 1986)

When applying the Heath-Carter method (Heath and Carter, 1967) to children, special attention must be paid to the fact that the rating forms for anthropometric somatotypes provide mesomorphy and ectomorphy scales adjusted for stature, but no similar adjustments for endomorphy and the sum of three skinfolds. However, when assuming that skinfolds decrease during growth in proportion to the increase in stature, it has been suggested that the sum of three skinfolds be multiplied by 170.18/stature (cm) before rating endomorphy in children (Carter and Heath, 1990; Hebbelinck *et al.,* 1973).

Previous research has shown that changes in somatotype in children can provide valuable information for understanding their growth and maturity (Claessens *et al.,* 2000; Toselli *et al.,* 1997). For example, Parizkova and Carter (1976) stressed the importance of assessing patterns of growth in individual children rather than relying on group means. In a comprehensive review of longitudinal studies on development and change in somatotype, Carter and Heath (1990) concluded that both individual and group somatotype changed with age and that individual patterns of change are important but could be masked by group variability.

In general, it is well known that males are more mesomorphic and less endomorphic at most ages in comparison with females, while in most studied samples, there are fewer differences in ectomorphy components between the sexes (Carter and Heath, 1990). Eiben and Németh (2001) underline that changes in proportions and body composition during puberty are mirrored in somatotypes. Many studies have investigated somatotypes of children in pubertal years (Carter *et al.,* 1997; Claessens *et al.,* 1985; Duquet *et al.,* 1993; Eiben and Németh, 2001; Hebbelinck *et al.,* 1995; Prokopec and Stehlik, 1988) and peculiarities of sexual maturation (Bodzár, 2000; Duke *et al.,* 1980; Lindgren, 1996; Macias-Tomel *et al.,* 2000; Marshall and Tanner, 1969, 1970) typically in terms of pubertal stages described by Tanner (Tanner, 1962). Studies in Estonian prepubertal (9- to 11-year old) children have shown that mesomorphic component in prepubertal children is the dominant one (Jürimäe *et al.,* 1999). With regard to gender-related differences, endomorphy was significantly higher in girls, while boys presented significantly higher values for the mesomorphy. No significant differences were observed in the ectomorphy component between boys and girls (Jürimäe *et al.,* 1999). The same gender-related differences were also observed in another study of 8–9-year-old pre-pubertal children of Estonia (Veldre, 1996). This is in accordance with the results of 8–9-year-old children in Hungary (Buday, 1990) and Belgium (Hebbelinck *et al.,* 1995).

In conclusion, there is considerable variation in somatotype among children and adolescents, and the differences between sexes lie greatly in the distribution of somatotypes in samples of boys and girls of different ages. Somatotype and

its variation are rather stable features of a person from late childhood on, being related to individual differences in the timing and tempo of the adolescent growth spurt and sexual maturation.

2.4. Methodology for the assessment of body composition

In the past five years, at least 27 articles in *Paediatrics* have included body composition variables from a variety of techniques, the majority from DXA (Sopher *et al.,* 2004). A major issue in the interpretation of body composition analysis is that different methods may yield different results for the same variable in the same person (Wang *et al.,* 2000; Hills *et al.,* 2001). This is true in both children and adults. In fact, absolute truth is not achievable with any *in vivo* technique for body composition because all are indirect and rely on numerous assumptions, never achieving the accuracy of direct actual chemical analysis (Goran, 1998; Hills *et al.,* 2001). However, methods vary in their accuracy, defined as their ability to approximate the "true" value for a given body component. A criterion method is one that is accepted as the closest representation of true body composition and is used as a standard against which other methods are compared (Sopher *et al.,* 2004). Body composition assessment involves quantification of the amount and relative proportions of fat, muscle and bone, and their chemical components (Hills *et al.,* 2001). Significant changes in body composition occur during growth and development, especially during infancy and puberty (Siervogel *et al.,* 1991).

Most simple methods, which use a two-component (2C) model dividing body mass into FM and FFM, use assumptions that ignore interindividual variability in the composition of FFM (Siri, 1961). Consequently, the measured values of FM and FFM are method dependent (Ellis, 1996; Hills *et al.,* 2001), making accuracy difficult to assess and hindering the comparison of different methods and studies. The lack of accurate data on body composition further hinders the evaluation of simple bedside techniques such as skinfold-thickness measurements and bioelectrical impedance analysis (BIA).

The three-component model (3C) includes FM but partitions FFM into total-body water (TBW) and fat-free dry mass (Roche *et al.,* 1996). Water is the largest component of body mass and the majority is located in the lean tissue. Fat-free dry mass includes protein, glycogen, bone mineral and soft tissue mineral (Withers *et al.,* 1999). TBW is often subdivided into the intracellular water (ICW-water that is within the cells) and extracellular water (ECW-water that is outside of the cells) (Hills *et al.,* 2001). TBW varies somewhat during the course of day, depending on fluid intake, physical activity level and on a hot day (Hills *et al.,* 2001).

The criterion method for body composition is the four-component (4C) model, combining measurements of TBW, body density and total body bone

mineral content (BMC) to estimate a fourth component — body fat%, fat mass, or fat-free mass (Heyward and Wagner, 2004; Roche *et al.,* 1996). The model divides body mass into fat, water, mineral, and protein, and allows evaluation of several assumed constant relations that are central to 2C models (Heymsfield *et al.,* 1990). These assumed constants include the water content, BMC, and density of FFM (Heymsfield *et al.,* 1990).

2.4.1. Methods for the measurement of body composition

Up to the present, the gold standard for measuring body composition in a 2C model has been **underwater weighing (UWW)**, which measures body density from which fat and lean mass content are estimated by assuming standard figures for the density of these components (Siri, 1961). The 2C model involving assessment of TBW is based on the assumption that the FFM has a constant and fixed hydration of 73.2% (Pace and Rathburn, 1945), which may in fact be influenced by factors such as gender and ageing (Baumgartner *et al.,* 1991). In addition, the classic 2C model approach involving measurement of total body density by UWW is based on the assumption that body mass is composed of 2 compartments, FM and FFM, and these compartments have fixed densities of 0.9 and 1.1 g/ml, respectively. In recent years, the UWW technique has begun to be replaced by **air-displacement plethysmography,** where the subject is immersed not in water but in a closed air-filled chamber (Dempster and Aitkens, 1995; McCrory *et al.,* 1995). However, all of the technical limitations related to the true volume that were noted for the UWW method remain. These instruments are designed for adults and will require significant modifications and improvements if the technique is to become useful for monitoring smaller subjects, including infants (McCrory *et al.,* 1998; Levenhagen *et al.,* 1999).

Dual-energy X-ray absorptiometry estimates the FM without making assumptions relative to lean mass, potassium concentrations or density, which are the bases for traditional methods such as underwater weighing, total body potassium counting and total body water techniques (Wellens *et al.,* 1994). DXA is becoming increasingly available for both clinical and research purposes and is considered as one of the most precise and applicable methods for measuring bone mineralization and body composition in paediatric populations (Gutin *et al.,* 1996; Ellis *et al.,* 1994; Pintauro *et al.,* 1996). DXA measurements are precise, require only moderate cooperation from the subject and deliver a very low radiation dose (Lewis *et al.,* 1994). These advantages make DXA an attractive tool for the investigation of body composition and bone mineral density in children. There are also concerns about the accuracy of DXA measurements, as different DXA machines may give varying results (Tothill and

Hannan, 2000). The advantages and limitations of the DXA method were presented by Genton *et al.* (2002). There are only a few studies where anthropometric measures (e.g., skinfold thicknesses, girths, lengths, breadths/ lengths) have been compared with body FM measured by means of DXA. Chumlea *et al.* (2002) studied the influence of frame size (bicristal, elbow, knee, biacromial and wrist breadths) on the total body fat in adult males and females. They concluded that the relationship is significant and seems to be more structural than substantive (Chumlea *et al.,* 2002).

Computed tomography (CT) technique uses X-rays that are collimated to provide a fan-shaped beam that is passed through the body, while an array of detectors is on the opposite side of the subject to detect the transmitted radiation. The X-ray source and detector assembly are rotated as a single unit around the subject covering a full 360^{o} (Baumgartner *et al.,* 1988). The major disadvantage of CT is the radiation dose required per slice for scanning (Goodpaster *et al.,* 2000). This may be the reason why this method has not widely been used in children.

Dilution method is performed by introducing orally or intravenously a certain substance like deuterium oxide, oxygen-18, or tritium (radioactive, not recommended) into the human body, and then collecting two body fluid samples (blood, urine, or saliva), one before introducing the tracer and second after an equilibration time of ~2–4 hours. Then the substance is equilibrated with water in the subject's body, and the density of the substance is analyzed. Dilution takes many hours of measurement and cannot be measured repeatedly. However, because it is rather accurate, it is used to measure body water for research purposes (Ellis, 2000).

Neutron activation analysis procedure allows for the direct elemental analysis of the living human body and is based on the principle that controlled neutron irradiation generates a known amount of radioactivity in a given substance of known mass. A major disadvantage of the neutron activation technique is that most of the dose is delivered to the body without the production of a useful signal (Morgan, 2000; Wang *et al.,* 2002).

The assessment of body composition in childhood can be performed with several sophisticated techniques as shown in (Table 1). However, in many circumstances, it is more desirable to utilize widely available and simple techniques (Table 2) such as the measurement of subcutaneous adipose tissue thickness. This would allow relatively quick determination of body composition without the need for specialized laboratories or expensive equipment (Hills *et al.,* 2001). On the other hand, variation in the relative distribution of adipose tissue is currently a topic of major interest in epidemiological analyses, where the relationships between adipose tissue distribution and risk for certain diseases have been studied (Malina *et al.,* 1999).

Use of **skinfold thickness** measurements to estimate %FM is particularly appealing in population studies because the procedure is relatively easy to perform, the measurements are noninvasive and do not involve radiation exposure, the measurements instrument (skinfold calipers) is inexpensive, does not require electrical power to operate, and the measurements can be done practically anywhere (Wang *et al.,* 2000). Skinfold thicknesses can be used as indicators of body fatness without predicting the size of body compartments. Skinfold caliper has been the most frequently used method of measuring subcutaneous adipose tissue thickness (Hills *et al.,* 2001). If the body fat distribution varies within individuals, it affects the accuracy and the measurement results. Therefore, the reliability of this method is relatively low compared with other methods (Wagner and Heyward, 1999). Lohman (1981) demonstrated that different caliper types may affect skinfold estimate.

Table 1. Laboratory methods for body composition assessment in children (compiled from Hills *et al.,* 2001; Jürimäe and Jürimäe, 2001).

Method	Advantages	Limitations	Recommendation to use in children
Underwater weighing	Directly measures total body density with excellent precision	Difficult maneuver to perform; expensive equipment; not practical for children	Not recommended for prepubertal children
Dual-energy X-ray absorptiometry	Could be used as a reference method; quick and simple; excellent precision for total body bone mineral; capable of regional assessment	Expensive equipment; different machines and software for different subjects	Highly recommended for children
Magnetic resonance imaging and computerized tomography scanning (CT)	Could be used as a reference method; very accurate; measures tissue area in specific anatomic locations;	Expensive and limited availability, CT involves some radiation	Recommended for pubertal children
^{40}K whole body counting	Good accuracy, safe, and non-invasive; permits a direct estimation of lean body mass	Expensive and limited availability; time consuming procedure	Recommended for children

To improve the accuracy of skinfold caliper measurements, several authors have also carried out *log* transformation of skinfold values (Parizkova, 1961; Durnin

and Rahaman, 1967). The main reasons for these transformations were skewed data, measurement errors being greater for thicker skinfolds than for thinner skinfolds, and, experimentally, skinfold measurements are not linearly related to body density.

Table 2. Field methods for body composition assessment in children (compiled from Hills *et al.,* 2001; Jürimäe and Jürimäe, 2001).

Method	Advantages	Limitations	Recommendation to use
Skinfolds and anthropometry	Quick and simple; inexpensive; useful for large sample groups; accurate for lean participants	Poor validity and large prediction errors	Recommended for children
Bioelectrical impedance analysis	Quick and simple; inexpensive; useful for large sample groups	Need to have information on hydration status of fat-free mass	Highly recommended for children
Computerized optical system (LIPOMETER)	Precise and simple; inexpensive; useful for large sample groups	Requires high degree of technical skill	Highly recommended for children

Bioelectrical impedance analysis is a safe, portable, non-invasive, rapid and inexpensive method of determining body composition (Lukaski, 1991). There is evidence that BIA is more accurate in measuring %FM than BMI in both adults (Sun *et al.,* 2003) and children (Jürimäe *et al.,* 2001a; Pecoraro *et al.,* 2003). BIA is based on the relationship between the volume of the conductor (i.e. the human body), the conductor's length (i.e. the subject's height), the components of the conductor (i.e. fat or FFM) and its impedance (Brodie *et al.,* 1998). However, the intracellular penetration is not complete at the frequency of 50 kHz. Differences in the distribution of fluid between infra-and extracellular compartments which occur during growth and development could help explain the variability in the prediction of fluid status or change in fluid status in children. The new impedance instruments are able to measure body impedance at more than one frequency, ranging from low (about 1 kHz) to very high (>1 mHz) (Deurenberg, 1995). At low frequency, body impedance is a measure of ECW and at high frequency body impedance is a measure of ICW. Body impedance measured at the traditional constant frequency of 50 kHz primarily reflects the amount of TBW (Kushner, 1992; Hills *et al.,* 2001). Jürimäe *et al.* (2001b) indicated that all nine skinfold thicknesses measured by caliper correlated significantly with body impedance at 50 kHz in 9- to 11-year-

old girls (r=–0.20 to r=–0.35), while only *iliac crest, supraspinale* and *mid-axilla* sites correlated significantly with body impedance in the same aged boys. However, stepwise multiple regression analysis indicated that the importance of skinfold thicknesses for characterizing body impedance was low (Jürimäe *et al.,* 2001b). Different segments of the body contribute to the impedance of the whole body to an extent that is out of proportion to their contribution to body weight (Fuller and Elia, 1989; Chumlea *et al.,* 1988). For example, the arm contributes only about 4% of body mass but as much as 45% to the resistance of the whole body in adults (Fuller and Elia, 1989). The thinner segments of the body provide the greatest resistance, especially when these segments are also long (Fuller and Elia, 1989). The influence of different anthropometric variables on the body impedance in children is poorly studied. Recently, Maste *et al.* (2002) concluded that there are inconsistencies in the BIA and anthropometrical measurements of FM in prepubertal children. However, the percentage of body water in boys from birth to 10 years of age has been reported to decrease as does the ratio of ICW to ECW (Fomon *et al.,* 1982). Variation in hydration of FFM is relatively high in children (Hewitt *et al.,* 1993).

A new **computerized optical system** ("LIPOMETER") has been developed in order to permit a non-invasive, quick, precise, and safe determination of subcutaneous adipose tissue (SAT) thicknesses at 15 specific body sites (Möller *et al.,* 1994, 2000a). Subcutaneous adipose tissue topography (SAT-top) is measured for about 2 min which is quicker when compared with skinfold thickness measurements on 10 body sites made with a skinfold caliper. The LIPOMETER measures a single, not compressed, SAT (Möller *et al.,* 1994, 2000a,b,c). To our knowledge, this measurement method has not been used to assess body composition in children during puberty.

In conclusion, several specific methods are used for the measurement of body composition. They all have smaller or bigger measurement errors. Some of them are not useable for testing children. Several regression equations are presented for calculating different components of body composition. However, it has to be considered that from the statistical point of view is not acceptable to compare different methods only by using simple correlations and at least the upper and lower limits of agreement using Bland and Altman method is necessary (Williams and Bale, 1998).

2.4.1.1. Body composition in children

There is a growing recognition of a need to measure body composition in children. *First*, the rise in the prevalence of childhood obesity (Hughes *et al.,* 1997) has increased the demand for accurate methods for determining body fatness in younger age groups. *Second*, the measurement of body composition is important for optimum clinical care during hospitalization because the size of

the FFM is an important index of energy and fluid requirements during artificial nutrition (Hills *et al.,* 2001; Lohman, 1992). *Third*, measurements of body composition aid in the assessment and treatment of childhood growth disorders (Kehayuas and Valtuena, 1999). Despite these recognized needs, body composition in children remains difficult to measure with accuracy and precision.

The assessment of body composition has traditionally been based on the 2C model (body is divided into FM and FFM) (Behnke and Wilmore, 1974; Brozek *et al.,* 1963; Siri, 1956). However, as children have more body water and relatively less total bone mineral compared with adults (Lohman *et al.,* 1984) and the chemical composition of FFM varies throughout the maturation process, the traditional 2C model overestimates the body fat (Reilly, 1998). Thus, for the assessment of body composition in children, it is necessary to use a multi-compartment model (Hills *et al.,* 2001), which involves the measurement of several components of body composition (Elia, 1992; Lohman, 1993; Houtkooper *et al.,* 1996).

The relationships between children's physical activity, aerobic fitness, and body fatness are not clear. If energy expenditure is reported, it should be adjusted for body size, because the cost of moving the body increases with body size (Ward and Evans, 1995). Problems with adjusting energy expenditure to account for differences in body size can lead to spurious results; hence, the appropriate scaling method has to be selected and interpreted with caution (Goran, 1997). Bar-Or and Baranowski (1994) have recommended that, when the relationship to adiposity is being determined, physical activity measures should be expressed as body movement and not as energy expended. They concluded that obese children tend to be less physically active than their non obese counterparts. When total energy expenditure (normalized for fat free mass) is measured, as opposed to the behavioral aspect of physical activity, there appears to be no difference between obese and non obese children (Goran, 1997). This highlights the importance of differentiating between physical activity and energy expenditure. It is unclear which aspects of physical activity are important in regulating body weight. Hence it is important to measure as many of these factors as possible. Goran (1997) has suggested intensity, activity time, metabolic efficiency, overall energy cost, and the type of physical activity as important factors for consideration. Measuring body composition is an effective tool for determining the success of and compliance with a weight control program in growing children and adolescents (Wile and McIntyre, 1993).

2.4.1.2. Assessment of body composition during puberty

In children older than two years of age, BMI is highly correlated with %FM (Maynard *et al.,* 2001), but differs in children with different ethnic backgrounds (Deurenberg *et al.,* 2003) and performs better than other weight-for-height measures for this purpose (Mei *et al.,* 2002). However, BMI does have some unique limitations in children. In children, BMI is correlated with height at some ages, most notably in 10- to 14-year-old boys (Maynard *et al.,* 2001). Consequently, in this age range, BMI is partly an indicator of the overall size as well as body composition. The use of a triceps skinfold measurement in combination with BMI is likely to give a more accurate categorization of adiposity and has been proposed for the determination of overweight in children of 10 years of age and older (Himes and Dietz, 1994). The utility of BMI to identify children at risk for undernutrition has not been assessed. In developing nations where chronic undernutrition is prevalent, weight-for-height measures can appear from normal to high in the presence of stunting and low body fat reserves (Trowbridge *et al.,* 1987). Finally, the BMI has been found to be more a function of muscle and bone mass than fatness in adult Canadian males (Ross *et al.,* 1988).

Total body FM, FFM and %FM can be estimated using anthropometric prediction equations developed from samples of healthy children (Durnin and Rahaman, 1967; Durnin and Womersley, 1974; Slaughter *et al.,* 1988). Some prediction equations include race, obesity and pubertal status. The selection of the appropriate prediction equation is based on the child's age and gender. Anthropometric prediction equations are best used to evaluate groups of children rather than individuals (Hills *et al.,* 2001). The triceps skinfold thickness is particularly useful because of its sensitivity to fluctuations in nutritional status, its high correlation with total body fat stores, and the availability of excellent reference data for individuals from one year of age through adulthood (Frisancho, 1981; Shephard, 1991). The subscapular skinfold measure is informative because it is a good measure of adiposity on the trunk, and it is highly correlated with health risk (Rolland-Cachera, 1995). The sum of *triceps* and *subscapular* skinfolds is a good indicator of overall fatness (Frisancho, 1981, 1990). In case of obese children, the accurate measurement of skinfold thickness is not always possible. Indices of fatness and fat distribution, such as skinfold ratios, have even lower precision than direct measurements due to the compounding of measurement errors (Mueller and Kaplowitz, 1994). However, in using skinfold measures to predict body composition, Durnin *et al.* (1971, 1997) have shown that inter-observer differences in measurement technique have only a small effect on the prediction of body fat.

As in adults (Lohman, 1992), the measurement of body composition in children (Davies *et al.,* 1988; Kuschner, 1992) by using BIA has utilised the resistance index (RI) in different equations ($RI = height^2/R$). Houtkooper *et al.* (1989) have reported that RI, in conjunction with body mass, accurately

predicted FFM in children aged 10–14 years. Danford *et al.* (1992) indicated that RI was the single most significant predictor of total body water, accounting for 97% of the total variability in 5–9 year old healthy children. However, Delozier *et al.* (1991) reported that stature and body mass were better predictors of total body water than RI in children aged 4–8 years. Probably the squaring the stature of "short" subjects did not result in as large a range of values for the RI.

The assessment of body composition in children can be done by using several available and simple techniques (e.g., anthropometry, BIA) or other methods that may need special laboratory equipment (deuterium oxide dilution), expensive equipment (DXA, CT scanning) and/or may be impractical for children (UWW). The following paragraph summarizes the most common body composition methods used in children.

2.5. Reproducibility of anthropometrical measurements and body composition parameters during puberty

As with any use of quantitative biological measure, it is important to minimize error, and to know and understand the various ways in which it is estimated and assessed. The ability to accurately compare or track changes in anthropometric variables is critically dependent on the reproducibility of the measurement, which reflects both trial-to-trial reproducibility as well as day-to-day biological variability (Wilmore *et al.*, 1997).

In longitudinal studies, possible errors are associated with: 1) repeated measures that give the same value (unreliability, imprecision, undependability); and 2) measurements that depart from true values (inaccuracy, bias). Imprecision is mainly caused by observer error, and is the most commonly used measure of anthropometric measurement error. This can be estimated by carrying out repeated anthropometric measures on the same subjects and calculating one or more of the following: technical error of measurement (TEM); percentage TEM, coefficient of reliability (R), and intraclass correlation coefficient. It is difficult to identity acceptable levels of measurement error because TEM is age dependent, and the value is also related to the anthropometric characteristics of the studied group or population. $R>0.95$ should be sought where possible (Ulijaszek and Kerr, 1999). This knowledge has potential diagnostic value since most child survival, health and development programmes include regular growth monitoring (Tomkins, 1994) and monitoring of nutritional status by using different anthropometric parameters (World Health Organization, 1995).

Motivated by the work of Brozek and Keys (1951) and Keys and Brozek (1953), the measurement of subcutaneous fat with skinfold calipers has become

a routine laboratory and field method. Caliper measurement of skinfold thickness has several limitations, which may highly decrease the reproducibility, i.e., differences between calipers and measurement sites (Cameron, 1984; Lohman *et al.,* 1988). It is important to note that soft tissue generally is more difficult to measure accurately than the basic measurements of linear growth and body mass. In addition, it has to be considered that the accuracy and reproducibility of skinfold thickness measures decline with increasing adiposity (Hills *et al.,* 2001).

Bouchard (1985) has reported intraclass correlations (ICC) ranging from r=0.94 to r=0.98 for six skinfold measurements in 61 children and adults of both sexes for replicate measures taken within a two-week period. Mueller and Malina (1987) reported ICCs as estimates of reproducibility for five skinfold measurement sites in 77 adolescents within a period of three weeks and found that the ICCs ranged from r=0.88 to r=0.98, while Pollock *et al.* (1976) conducted report measurements on 18 young and middle-aged men and reported reproducibility estimates of r=0.96 to r=0.99 for different skinfolds. Technical errors reported by Bouchard (1985) were between 1.0 mm and 2.1 mm for six different skinfolds, while Wilmore *et al.* (1997) found TE to be ≤ 1.0 mm for measured skinfolds in their studies.

There is less information about the reproducibility of girth, length and breadth/length parameters. However, the works of Boileau *et al.* (1981) and Slaughter *et al.* (1978) show that this approach produces only slightly larger standard error of estimates (SEEs) for these parameters than do skinfolds. Wilmore and Behnke (1969) reported ICCs ranging from r=0.98 to r=0.99 and Pollock *et al.* (1976) from r=0.95 to r=0.99 for girth parameters in men, while tehnical error (TE) for length and girth values were generally ≤ 1.0 cm and coefficient of variation (CVs) < 1% (Wilmore *et al.* 1997).

The Heath-Carter anthropometric somatotyping protocol is a reliable method for assessing the physique of prepubertal children (Jürimäe *et al.,* 2000). Our study demonstrated that the assessment of the physique using the Heath-Carter anthropometric somatotyping method for endo-, meso- and ectomorphy components measured within one week appears to be an accurate and valid procedure suitable for prepubertal boys and girls (ICC ranging r=0.89 to r=0.99 and SEE<0.4) (Jürimäe *et al.,* 2000).

Bioelectrical impedance measurements are highly reliable based on interobserver and intraobserver comparisons with replacements of electrodes as well as on interday and interweek comparisons (Baumgartner *et al.,* 1990; Gutin *et al.,* 1996; Jackson *et al.,* 1988; Kuschner, 1992; Lukaski *et al.,* 1985; Wu *et al.,* 1993). The measurement of body water compartments with multifrequency bioelectrical impedance in children and adults is also an accurate and valid procedure (Baumgartner *et al.,* 1990; Gutin *et al.,* 1996; Jackson *et al.,* 1988; Wu *et al.,* 1993).

In summary, the reproducibility of skinfold thickness and BIA measurements appears to be an accurate and valid procedure for children in different

ages. However, less information is available about the reproducibility of girth, length and breadth/length measurements in children during puberty. Furthermore, to our knowledge, no studies have been performed that have investigated longitudinally the possible changes in reproducibility in anthropometric and BIA parameters throughout puberty in boys and girls.

3. AIMS OF THE INVESTIGATION

The general aim of the present investigation was to study longitudinally the development of the anthropometrical and body compositional parameters of human body (growth) during puberty and to present some new aspects about the influence of the quality of measurement on anthropometrical parameters and body composition in Estonian boys and girls.

Accordingly, the specific aims of the present study were:

1. to characterize the changes in skinfold thickness, girth, length, breadth/ length and body impedance parameters during puberty;
2. to study longitudinally the changes of the reproducibility of anthropometrical and body compositional parameters during puberty;
3. to study the influence of specific anthropometrical parameters and somato-type on the body composition measured by bioelectrical impedance analysis or dual-energy X-ray absorptiometry;
4. to assess the relationships in body composition between skinfold thickness measured by skinfold caliper and LIPOMETER with dual-energy X-ray absorptiometry.

4. MATERIAL AND METHODS

4.1. A summary of the aims, numbers of subjects and methods used in the studies

Study I: The aim of the study was to investigate the changes in the anthropometrical parameters and body impedance during four years of the pubertal time in boys and girls.

Study II: The aim of the study was to establish the reproducibility of a series of anthropometric measures performed twice during one week over a three year period in boys and girls.

Study III: The aim of the study was to investigate the influence of anthropometric measures on the whole body impedance and impedance index and the body fat mass measured by means of DXA in children.

Study IV: The aim of the study was to compare the relationships between bioelectrical impedance and thicknesses of adipose tissue measured by traditional skinfold caliper (double thickness) or a LIPOMETER device (single non-compressed thickness).

Table 3. A short summary of the number of subjects and methods used in the studies.

	Study I	Study II	Study III	Study IV
The subjects (all subjects were chosen by random selection)	81 boys 86 girls	21 boys 18 girls	26 boys 27 girls	52 boys 44 girls
Age (yrs)	First year 10–11	First year 9–10	11–12	9–12
Biological age by Tanner (1962)	X	X	X	
Physical activity index	X			X
Anthropometry by ISAK	X	X	X	X
Somatotype by Heath-Carter	X		X	
Measurement of SAT-layers by LIPOMETER				X
Body impedance	X		X	X
Impedance index	X		X	
Body composition by DXA			X	

4.2. Subjects

Study I

At the beginning of the longitudinal study, 104 boys and 105 girls of the age 9–11 years were approached and investigated during the first year of study. Number of complete cases was 81 and 86 for boys and girls respectively (Table 4). All children were in Tanner stage 1 (Tanner, 1962) at the beginning of the study. They were measured once a year in January and February over four years. The subjects were from several schools of Tartu (Estonia) and all children were of Estonian origin. The children were healthy. Their school physical education consisted of two obligatory physical education classes per week. All children, parents and teachers were thoroughly informed of the purposes and contents of the study and written informed consent was obtained from the parents or the adult probands before participation. This study was approved by the Medical Ethics Committee of the University of Tartu (Estonia).

Table 4. Mean (±SD) anthropometrical parameters of subjects who completed Study I.

	Boys (n=81)	**Girls (n=86)**
Age (yrs)	10.0±0.8	9.9±0.7
Height (cm)	142.8±7.3	141.7±7.4
Body mass (kg)	34.8±5.6	33.4±6.6
BMI (kg/m^2)	17.0±1.8	16.5±2.2

Study II

The reproducibility of anthropometric and BIA measurements was performed in a subset of the studied sample. Based on random selection, the subjects of this investigation were 39 children (21 boys and 18 girls), 9–11 years of age at the beginning of the study (Table 5). Children were measured three times with in a one-year interval and every year they were tested two times within one week interval by the same investigator using the same equipment. Children were classified by Tanner stage 1 during the first measurements, stage 2–3 during the second measurements and stage 3–4 during the third measurements (Tanner, 1962).

Table 5. Mean (±SD) anthropometrical parameters at the beginning of Study II.

	Boys (n=21)	**Girls (n=18)**
Age (yrs)	10.2±0.8	9.6±0.6
Height (cm)	143.7±6.7	140.4±7.4
Body mass (kg)	36.3±6.2	32.7±6.0
BMI (kg/m^2)	17.5±2.0	16.4±1.9

Study III
In another subset of the studied sample, the influence of anthropometric parameters (nine skinfolds, 13 girths, eight lengths, and eight breadths/lengths) on the body composition measured by BIA and DXA was investigated. The subjects of this investigation were 11- to 12 years-old boys and girls (Table 6). All children were in Tanner (1962) stages 2–3.

Table 6. Mean (±SD) anthropometrical parameters at the beginning of Study III.

	Boys (n=26)	Girls (n=27)
Age (yrs)	12.2±0.7	11.8±0.7
Height (cm)	156.5±7.2	152.8±8.5
Body mass(kg)	45.2±8.3	39.4±6.3
BMI (kg/m^2)	18.4±2.5	16.8±1.5

Study IV
The relationships between BIA and subcutaneous adipose tissue thickness measured by skinfold calipers and LIPOMETER were also studied in a subset of the studied sample. The subjects of this study were 10- to 12-year-old boys and girls (Table 7). Children in this study were in Tanner (1962) stages 2–3.

Table 7. Mean (±SD) anthropometrical parameters at the beginning of Study IV.

	Boys (n=52)	Girls (n=44)
Age (yrs)	11.6±0.8	11.2±0.9
Height (cm)	146.5±9.0	146.4±8.9
Body mass (kg)	39.8±6.6	37.9±7.4
BMI (kg/m^2)	17.5±1.9	17.0±2.3

4.3. Sexual maturation

Pubertal status of the subjects was assessed by Tanner (1962) stages using pubic hair in both, boys and girls. The self-assessment for the evaluation of pubic hair was used (Beunen and Malina, 1996). Each subject was asked to observe photographs (Marshall and Tanner, 1969, 1970) of the stages of secondary sex characteristics and also to read the descriptions of stages. Most of the subjects assessed their pubertal status by themselves; some of them had their status assessed by the author of the present thesis.

4.4. Anthropometric measurements

Body height was measured using Martin metal anthropometer in cm (± 0.1 cm) and body mass with medical scales in kg (± 0.05 kg). Body mass index (kg/m^2) was calculated. In total, nine skinfolds (*triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, medial calf, mid-axilla*), 13 girths (*head, neck, arm relaxed, arm flexed and tensed, forearm, wrist, chest, waist, gluteal, thigh, mid-thigh, calf, ankle*), eight lengths (*acromiale-radiale, radiale-stylion, midstylion-dactylion, iliospinale, trochanterion, trochanterion-tibiale laterale, tibiale laterale, tibiale mediale-sphyrion tibiale*) and eight breadths/lengths (*biacromial, biiliocristal, foot length, sitting height, transverse chest, anterior-posterior chest depth, biepicondylar humerus, biepicondylar femur*) were measured according to the protocol recommended by the ISAK (Norton and Olds, 1996). Skinfold thicknesses were measured in triplicate using Holtain (Crymmych, UK) skinfold caliper. For each skinfold, the mean of all three trials was taken as the final measurement. The CENTURION KIT instrumentation (Rosscraft, Surrey, BC, Canada) was used for girth, length and breadth/length measurements. The series of anthropometric measurements were conducted by the same well-trained anthropometrist (Level 1 ISAK anthropometrist).

4.5. Calculation of somatotype components

Three somatotype components — endomorphy, mesomorphy and ectomorphy — were assessed according to the Carter and Heath (1990) anthropometric somatotyping method modified for children (i.e., height-corrected endomorphy):

Endomorphy $= -0.7182 + 0.1451\ X - 0.00068\ X^2 + 0.0000014\ X^3$

Mesomorphy $= 0.858\ HB + 0.601\ FB + 0.188\ AG + 0.161\ CG - 0.131\ SH + 4.5$

Ectomorphy
$= 0.732\ HWR - 28.58$ (If $HWR > 40.74$)
$= 0.463\ HWR - 17.615$ (If $39.65 < HWR \leq 40.74$)
$= 0.5$ (If $HWR \leq 39.65$)

Where: X = sum of three skinfolds (*triceps, subscapular, supraspinale*)(mm), (for application to children, X is multiplied by 170.18/height (cm) to yield height-corrected endomorphy; HB = humerus breadth (cm); FB = femur breadth (cm); AG = corrected arm girth (cm); CG = corrected calf girth (cm); SH = standing height (cm); HWR = height (cm) over cube root of weight (kg) (Adapted from Duquet and Carter, 1996; Malina, 1995a).

The combined rating of each component describes an individual's somatotype. If one of the components is dominant, the individual's somatotype is described by that component.

4.6. Bioelectrical impedance analysis

Body impedance was measured on the right side of the body using a multiple-frequency impedance device (Multiscan 5000, Bodystat, UK) at standard conduction current of 800 μA and 50 KHz and the impedance index was calculated (height^2/ impedance). The accuracy of the equipment was checked before the measurements with a 500 Ω resistor supplied by the manufacturer. Children were placed in a supine position with limbs slightly abducted. Skin current electrodes were placed on the dorsal surface on the hand and foot at the metacarpals and metatarsals. Skin was cleaned with 70% alcohol and a small drop of EKG cream was used to improve current conduction between the electrode and skin.

4.7. Computerized optical system (LIPOMETER)

Measurements were performed by means of the optical device LIPOMETER (Möller *et al.,* 1994, 2000a). LIPOMETER uses light-emitting diodes, which illuminate the SAT-layer of interest, forming certain geometrical patterns varying in succession. A photodiode measures the corresponding light intensities back scattered in the subcutaneous adipose tissue. The light signals are amplified, digitized and stored on computer. Measurements for the thickness of SAT-layer (in mm) were performed at 15 original body sites (*neck, triceps, biceps, upper back, front chest, lateral chest, upper abdomen, lower abdomen, lower back, hip, front thigh, lateral thigh, rear thick, inner thigh, calf*) on the right side of the body in the standing position (Möller *et al.,* 1994, 2000a). The CVs of SAT-layers range between 1.9% for SAT-layer front chest and 12.2% for SAT-layer rear thigh (Möller *et al.,* 2000b). The sum of 15 SAT-layers was calculated.

The research was conducted in Tartu in cooperation with the scientists from the University of Graz, Austria and the measurements with LIPOMETER were made by Professor Dr. Karl Sudi.

4.8. Dual-energy X-ray absorptiometry

Whole-body dual-energy X-ray absorptiometry using the DPX-IQ densitometer (Lunar Corp; Madison, WI, USA, software version 3.6) was used for body composition assessment. Children were scanned from head to toe in 10–15 min. Total body FM and separate hands, legs and trunk FMs were estimated. Hands FM relationships (using stepwise multiple regression analysis) separately from corresponding skinfolds (*triceps, biceps*), girths (*arm relaxed, arm flexed and tensed, forearm, wrist*), lengths (*acromiale–radiale, radiale–stylion, midstylion-dactylion*) and breadths/lengths (*humerus*) were studied. Legs fat mass compared with corresponding skinfolds (*front thigh, medial calf*), girths (*thigh, mid thigh, calf, ankle*), lengths (*iliospinale–box height, trochanterion–box height, trochanterion–tibiale laterale, tibiale-laterale to floor, tibiale mediale–sphyrion tibiale*), breadths/lengths (*foot lengths, femur*) was studied. *Sub-scapular, iliac crest, supraspinale, abdominal* and *midaxilla* skinfolds, *head, neck, chest, waist* and *gluteal* girths and *biacromial, biiliocristal, sitting height, transverse chest* and *A-P chest depth* breadths/lengths were related to trunk FM.

The measurements were executed in the bone density laboratory of Tartu University Hospital and the assessments were made by an experienced technician.

4.9. Assessment of physical activity

The physical activity index (PAI) of children was estimated according to the questionnaire of Telama *et al.* (1996).

4.10. Statistical analysis

Table 8. A summary of the statistical methods used in the studies.

	Study I	Study II	Study III	Study IV
Mean ± SD	X	X	X	X
TE		X		
CV		X		
ICC		X		
Unpaired two tailed t-test	X			
Independent t-test				X
Stepwise multiple regression analysis			X	X
Spearman correlation	X			
Pearson correlation				X
Bland and Altman method				X

Data analysis was performed using SPSS 10.0 for Windows (Chicago, IL, USA). Standard statistical methods were used to calculate mean ±SD. An unpaired two-tailed t-test was used to assess differences between boys and girls. The interperiod Spearman correlations were used as tracking coefficients (Study I). Technical errors (TE), CV, and ICC were computed to evaluate the reproducibility of anthropometrical parameters (Norton and Olds, 1996) (Study II). Technical error was defined as the SD of repeated measurements made independently of one another on the same subject. The units of the TE are the same as the units of the variable measured (%TE=TE/mean x 100), where mean is the overall mean of the variable that has been measured. The relative TE gives the error as a percentage of the overall mean and has no units. In other contexts, the%TE may be referred to as the coefficient of variation of the variable. The measure of reliability is the ICC, which indicates the correlation between successive measurements on the same subject. An ICC value range from 0 to 1, with a value close to 1 indicating high reliability since successive measurements are then in relatively close agreement. The ICC of measured anthropometric parameters provides an indication of the predictive value of the measurement by accounting for the population variance, while the TE is a measure of the magnitude of the error, and the CV is a measure of the magnitude of the error relative to the magnitude of the measurement (Norton and Olds, 1996). Pearson correlation coefficients were used to determine the relationships between continuous dependent variables (Study I). The effect of different anthropometrical parameters to the body resistance and resistance index and body fat mass measured by DXA was analyzed using stepwise multiple regression analysis (Study III). The general regression included all the measured nine skinfolds, thirteen girths, eight lengths and eight breadths/lengths variables. Prediction errors for the equations were evaluated using SEEs (Study II). Methodological differences in the estimates of three skinfold thicknesses and subcutaneous adipose tissue layers (*biceps, triceps, front thigh*) were also analyzed by the method of Bland and Altman (1986) (Study IV). The level of significance was set at $p < 0.05$.

5. RESULTS

5.1. Longitudinal changes in different anthropometrical parameters during puberty (Study I)

Mean (±SD) basic anthropometrical parameters, somatotype components, PAI and Tanner stage results in boys (n=81) and girls (n=86) are presented in Table 9. Body height and body mass increased significantly ($p<0.05–0.01$) during every year both in boys and girls. However, BMI increase in girls between the third and fourth measurement was not significant ($p>0.05$). From the somatotype components, ectomorphy did not change significantly during the study period. In boys, the endomorphy was lowest during the first measurement ($p<0.05–0.01$). In girls, the changes were not significant ($p>0.05$). Mesomorphy in boys did not change significantly; in girls, the index was significantly higher during the first measurement. PAI did not change significantly during the pubertal period. The present study confirmed the previous results that during puberty, the changes in anthropometry are very quick and on the other hand, there is significant interindividual variation in the timing and tempo of puberty (Table 10). Tanner stage increased significantly ($p<0.01–0.001$) every year. For sample, girl no.I, in early puberty, with a high BMI — a classical example of early puberty in obese girls. II and III girl as samples of late puberty (Table 11). Boys I and II as relatively late but normal developers and III and IV as fast developers (Table 12).

The changes of the skinfold thicknesses, girths, lengths and breadths/lengths during four years are presented in Tables 13–16. All the measured skinfold thicknesses increased significantly between the first and second measurement. At the end of puberty, especially in boys, some skinfold thicknesses decreased significantly. Except that of the head, as a rule, other girths increased significantly. There are more significant increases in length and breadth/length parameters at the end of puberty (between the second and third and the third and fourth measurements).

In boys, the changes in body impedance were significant between the measurement years (Table 17). The body impedance decreased except between the second and third measurements. In girls, the increase in the impedance between the second and third measurement was not pronounced ($p>0.05$). In both boys and girls, the impedance index increased significantly every year ($p<0.05–0.001$).

Table 9. Mean (± SD) anthropometrical parameters, somatotype components, physical activity and Tanner stages during four years, girls in *Italic*.

	First measurement	Second measurement	Third measurement	Fourth measurement
Age (yrs)	10.0±0.8 *9.9±0.7*	10.9±0.8 *10.8±0.8*	12.0±0.8 *11.9±0.8*	12.9±0.8 *12.8±0.8*
Height (cm)	142.8±7.3 *141.7±7.4*	148.5±7.8* *147.5±8.2**	155.1±8.9*¤ *153.8±8.0**¤	162.0±10.2*¤# *159±7.6**¤#
Body mass (kg)	34.8±5.6 *33.4±6.6*	39.3±7.2* *37.2±7.9**	45.0±9.2*¤ *42.4±9.2**¤	50.2±10.8*¤# *46.4±9.6**¤#
BMI (kg/m²)	17.0±1.8 *16.5±2.2*	17.7±2.1* *17.0±2.4**	18.5±2.7*¤ *17.9±3.0**¤	19.0±2.8*¤# *18.2±2.8**¤
Endomorphy	2.1±0.9 *2.6±1.3*	2.7±1.2* *2.8±1.6*	2.6±1.5 *2.8±1.5*	2.5±1.4 *2.9±1.5*
Mesomorphy	4.2± 0.9 *3.8±0.9*	4.1±1.1 *3.5±0.9**	4.3±1.1 *3.5±1.0*	4.3±1.2 *3.3±1.0*
Ectomorphy	3.5±1.1 *3.8±1.3*	3.5±1.3 *4.0±1.4*	3.6±1.4 *3.9±1.4*	3.8±1.4 *4.0±1.4*
PAI	11.7±1.4 *11.6±1.8*	11.7±1.5 *11.8±1.4*	11.8±1.3 *11.9±1.4*	11.8±1.5 *11.8±1.6*
Tanner stage	1–2 *1–3*	1–3* *2–4**	2–4*¤ *2–4**¤	2–4*¤# *2–4**¤#

BMI — body mass index;
PAI — physical activity index;
* significantly different from the first measurement ($p<0.05–0.01$);
¤ significantly different from the second measurement ($p<0.05–0.01$);
significantly different from the third measurement ($p<0.05–0.01$).

Table 10. Interindividual variation in the timing and tempo of puberty in girls and boys.

Tanner stage	First measurement		Second measurement		Third measurement		Fourth measurement	
	boys	girls	boys	girls	boys	girls	boys	girls
1	75	72	50	34	10	12	1	
2	6	13	29	42	52	36	16	18
3			2	9	16	27	30	40
4		1		1	3	11	27	24
5							7	4

Table 11. Extreme examples of girls with different Tanner stages and anthropometrical parameters.

Girls	**Sample I**				**Sample II**				**Sample III**			
Tanner stage	4	4	4	4	1	1	1	2	1	1	1	3
Age	11	12	13	14	10	11	12	13	9	10	11	12
Height	154.1	157.5	158.5	160.0	133.30	137.50	140.70	145.10	137.2	142.0	145.9	153.5
Body mass	53.3	58.3	60.5	61.8	27.30	30.35	31.90	35.20	27.1	28.8	31.9	34.3
BMI	22.44	23.51	24.08	24.14	15.36	16.06	16.11	16.72	14.41	14.26	14.98	14.56
Sum of 9 skinfolds	161.1	192.7	166.0	174.0	66.00	70.20	71.00	70.00	57.0	63.1	57.0	59.0

BMI — body mass index; sum of 9 skinfolds — sum of *triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, medial calf, mid-axilla* skinfolds

Table 12. Extreme examples of boys with different Tanner stages and anthropometrical parameters.

Boys	**Sample I**				**Sample II**				**Sample III**				**Sample IV**			
Tanner stage	1	1	1	2	1	1	1	2	2	2	3	5	1	1	2	5
Age	9	10	11	12	9	10	11	12	11	12	13	14	10	11	12	13
Height	126.4	131.8	137.0	141.0	134.0	138.8	144.6	149.0	142.5	152,0	161.6	168.0	145.0	150.8	157.6	164.5
Body mass	26.4	28.6	33.0	35.0	26.8	29.8	32.7	34.8	38.6	45.0	55.5	59.9	35.8	37.9	43.7	49.2
BMI	16.50	16.49	17.58	17.70	14.90	15.47	15.64	15.68	19.01	19.50	21.26	21.22	17.05	16.70	17.59	18.15
Sum of 9 skinfolds	70.5	72.0	77.0	84.0	39.5	42.0	46.0	45.0	97.5	93.1	93.0	86.0	78.5	79.0	74.0	88.0

BMI — body mass index; sum of 9 skinfolds — sum of *triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, medial calf, mid-axilla* skinfolds

Table 13. Mean (±SD) skinfold thicknesses during four years, girls in *Italic*.

Skinfolds (mm)	First measurement	Second measurement	Third measurement	Fourth measurement
Triceps	9.9±2.9 *11.2±4.1*	11.5±4.2* *12.0±4.9**	10.5±5.1 *11.5±4.8*	10.0±4.1 *11.6±4.9*
Subscapular	7.1±3.2 *8.6±5.3*	9.2±4.5* *10.2±7.0**	8.7±5.4 *10.1±6.7*	8.7±5.6 *9.8±6.3*
Biceps	6.6±2.6 *7.6±3.6*	7.4±3.5* *7.8±3.8**	6.6±4.1 *7.1±3.5*	6.3±3.5* *8.0±3.6*
Iliac crest	8.4±4.4 *9.5±5.7*	11.0±6.4* *10.8±7.6**	11.1±7.6 *11.6±8.2**	10.8±7.6 *12.4±7.3**
Supraspinale	4.9±2.4 *6.3±4.1*	6.8±4.1* *7.5±6.0**	7.3±5.7 *7.6±5.7**	7.4±5.6 *7.9±5.4**
Abdominal	8.5±4.8 *9.9±6.4*	11.2±6.8* *11.3±8.6**	12.5±9.2 *12.0±8.4**	13.0±10.0 *13.1±8.0**
Front thigh	16.4±5.7 *18.5±7.1*	19.1±7.7* *20.0±7.8**	17.8±8.5 *19.4±7.6*	16.5±7.4 *19.7±7.3*
Medial calf	12.2±4.4 *13.3±5.5*	14.4±5.6* *14.8±6.2**	13.0±6.3 *14.2±5.9*	13.1±5.5 *14.9±5.7**
Mid-axilla	5.3±1.9 *6.3±3.9*	6.5±3.0* *7.2±5.0**	6.7±4.1 *7.5±5.8*	6.6±4.4 *7.4±5.0**

* significantly different from the first measurement ($p<0.05–0.01$).

Table 14. Mean (±SD) girths during four years, girls in *Italic*.

Girths (cm)	First measurement	Second measurement	Third measurement	Fourth measurement
Head	53.2±1.5 *52.6±1.6*	53.5±1.4 *52.8±1.6*	54.2±1.6 *53.4±1.6*	54.6±1.4 *53.7±1.5*
Neck	28.1±1.3 *26.8±1.4*	28.8±1.5* *27.2±1.6*	29.6±2.4*¤ *28.2±1.7*¤*	31.0±2.2*¤# *29.1±1.6*¤#*
Arm (relaxed)	20.1±2.0 *19.7±2.4*	21.0±2.4* *20.3±2.5**	22.2±2.4*¤ *21.2±2.7*¤*	23.3±3.0*¤# *22.1±2.7*¤#*
Arm(flexed and tensed)	21.7±2.0 *21.1±2.4*	23.0±2.4* *21.9±2.5**	23.9±2.8*¤ *22.6±2.7*¤*	25.4±3.1*¤# *23.5±2.7*¤#*
Forearm	19.7±1.4 *19.0±1.5*	20.5±1.7* *19.7±1.6**	21.7±1.8*¤ *20.5±1.8*¤*	22.8±2.0*¤# *21.2±1.5**
Wrist	13.5±0.9 *13.0±0.8*	13.9±1.0* *13.3±0.9**	14.5±1.1*¤ *13.8±0.9**	15.1±1.3*¤# *14.1±0.8*¤*
Chest	68.2±4.5 *66.3±6.0*	70.1±5.2* *68.1±7.1**	73.4±9.2*¤ *73.4±8.0*¤*	77.5±7.2*¤ *76.2±7.5*¤*
Waist	59.7±4.2 *56.6±5.3*	62.1±4.9* *57.8±6.0**	64.3±6.4*¤ *59.5±6.5*¤*	66.6±6.4*¤# *61.8±6.6*¤#*
Gluteal (hip)	71.4±5.3 *71.8±6.4*	75.2±6.2* *75.1±7.1**	78.9±7.3* *78.8±8.8**	82.0±7.4*¤ *83.1±7.7*¤#*

Table 14 (continued)

Girths (cm)	First measurement	Second measurement	Third measurement	Fourth measurement
Thigh	42.2±4.1 *42.4±5.0*	44.6±4.9* *44.2±5.0**	46.3±5.9* *46.2±5.8**	48.3±5.6*¤ *48.4±5.7*¤#*
Mid-thigh	39.0±3.4 *39.0±4.1*	41.4±4.2* *40.7±4.3**	43.9±5.4* *43.3±5.9**	45.5±4.9*¤ *45.2±5.2*¤*
Calf	28.3±2.3 *28.3±2.5*	29.8±2.7* *29.3±2.6**	31.1±3.3*¤ *30.7±2.8*¤*	32.4±3.3*¤ *31.7±3.0*¤*
Ankle	18.5±1.4 *18.3±1.4*	19.5±1.7* *18.9±1.5*	20.8±1.9*¤ *19.9±1.5*¤*	21.7±2.2*¤ *20.3±1.5*¤*

* significantly different from the first measurement (p<0.05–0.01); ¤ significantly different from the second measurement (p<0.05–0.01); # significantly different from the third measurement (p<0.05–0.01).

Table 15. Mean (±SD) lengths during four years, girls in *Italic.*

Lengths (cm)	First measurement	Second measurement	Third measurement	Fourth measurement
Acromiale-radiale	30.2±1.8 *30.1±1.9*	32.0±2.0* *31.6±2.2**	33.1±2.1*¤ *32.9±2.5*¤*	35.3±3.5*¤ *34.2±2.6*¤*
Radiale-stylion	22.8±1.6 *22.4±1.4*	23.6±1.5 *23.3±1.6*	24.7±1.7* *24.4±1.6**	26.1±1.9* *25.6±1.9**
Midstylion-dactylion	16.6±1.1 *16.0±2.0*	16.8±1.1 *16.7±1.1*	17.3±1.3* *17.1±1.3**	18.5±1.9* *18.1±1.6**
Iliospinale	82.1±5.1 *81.3±5.0*	84.7±5.4 *84.3±5.4*	89.3±5.3* *88.4±5.3**	93.1±6.3* *89.9±9.9**
Trochanterion	75.6±4.6 *74.9±5.6*	78.3±4.8 *77.8±4.8*	82.0±5.0* *81.7±5.2**	86.2±5.7* *84.8±5.0**
Trochanterion-tibiale laterale	38.8±2.7 *38.7±2.9*	40.1±2.3 *39.7±2.6*	42.3±2.8* *41.8±3.0**	44.2±3.2* *44.2±6.3**
Tibiale laterale	36.9±2.5 *36.5±2.6*	38.3±2.7 *38.2±2.4*	39.9±2.6* *39.7±2.4**	41.2±2.9* *40.2±2.5**
Tibiale mediale-sphyrion tibiale	29.3±2.4 *29.1±2.1*	31.5±2.3 *31.5±2.2*	33.3±2.5* *32.8±2.2**	34.5±2.4* *33.9±2.4**

* significantly different from the first measurement (p<0.05–0.01);
¤ significantly different from the second measurement (p<0.05–0.01);

Table 16. Mean (±SD) breadths/lengths during four years, girls in *Italic.*

Breadths/lengths (cm)	First measurement	Second measurement	Third measurement	Fourth measurement
Biacromial	31.7±1.9 *31.0±1.8*	33.1±2.2 *32.2±2.3*	34.7±2.6 *33.7±2.4*	36.8±2.8 *35.2±2.4*¤#*
Biiliocristal	21.9±1.5 *22.0±1.6*	23.3±1.7 *23.1±1.7*	24.5±1.9 *25.0±2.0*	25.9±2.2 *26.5±2.5*
Foot length	22.3±1.4 *21.9±1.3*	23.3±1.5 *22.7±1.3*	24.4±1.7 *23.3±1.3*	25.1±2.1 *23.9±1.3*
Sitting height	75.4±3.5 *74.6±1.3*	77.8±4.0* *77.1±4.3*	79.6±4.7*¤ *79.3±4.3*	83.3±5.5*¤# *82.9±4.0*#*
Transverse chest	21.9±2.8 *20.9±1.4*	22.7±1.6 *21.7±1.6*	23.5±1.9 *22.6±1.7*	24.9±2.1 *23.6±1.7*
Anerior-posterior chest depth	15.1±2.3 *14.2±1.2*	15.4±2.0 *14.7±1.5*	16.5±1.6*¤ *15.6±1.8*	17.3±1.7 *16.5±3.0*
Biepicondylar humerus	6.1±0.4 *5.8±0.4*	6.2±0.4 *5.9±0.4*	6.6±0.5 *6.2±0.4*	6.9±0.5*¤# *6.4±0.4*
Biepicondylar femur	8.8±0.5 *8.4±0.5*	9.0±0.5 *8.5±0.5*	9.5±0.6 *8.9±0.6*	9.8±0.5 *9.0±0.5*

* significantly different from first measurement ($p<0.05–0.01$);
¤ significantly different from second measurement ($p<0.05–0.01$);
significantly different from third measurement ($p<0.05–0.01$).

Table 17. Mean (±SD) body impedance and impedance indeces in boys and girls.

	First measurement	Second measurement	Third measurement	Fourth measurement
Body impedance (Ω)				
Boys	576.7±57.6	553.0±64.5*	557.8±71.0	543.2±78.1*
Girls	627.9±58.2	589.1±55.0*	623.7±68.1	608.8±61.5*
Impedance index (cm ²/Ω)				
Boys	35.9±5.7	40.6±7.1*	45.3±9.4*¤	50.0±12.2*¤#
Girls	32.5±5.1	37.5±6.2*	38.7±6.8*¤	42.1±6.6*¤#

* significantly different from the first measurement ($p<0.05–0.01$);
¤ significantly different from the second measurement ($p<0.05–0.01$);
significantly different from the third measurement ($p<0.05–0.01$).

5.2. Tracking of different anthropometrical and body composition parameters during puberty (Study I)

The tracking of body height (boys: r=0.938–0.986; girls: r=0.912–0.987), body mass (boys: r=0.905–0.957; girls: r=0.906–0.979) and BMI (boys: r=0.828–0.943; girls: r=0.814–0.926) is very high (Table 18) during puberty. The somatotype components tracking coefficients are also relatively high: ectomorphy (boys: r=0.817–0.933; girls: r=0.861–0.970), endomorphy (boys: r=0.693–0.901; girls: r=0.866–0.947) and mesomorphy (boys: r=0.780–0.882; girls: r=0.819–0.912). The tracking of PAI is relatively low (boys: r=0.272–0.446; girls: r=0.252–0.581). Compared with PAI, the tracking of Tanner stages is slightly higher (boys: r=0.314–0.683; girls: r=0.354–0.722).

The interperiod Spearman correlation coefficients of skinfold thicknesses are relatively high (Table 19). However, by increasing the time intervals between the measurements, the tracking coefficients decreased rapidly. As a rule, during four years (from 10 to 13), the tracking coefficients decreased about 0.2 units. The tracking of the girth is quite high and the differences between the years are relatively low (Table 20). Normally, the changes in four years are relatively stable. Similar changes occurred in the length parameters (Table 21). From the detailed measured anthropometrical parameters the tracking is lowest in the breadth/length parameters (Table 22). The tracking of both body impedance and impedance index is high and decreased slightly with increasing the time interval between the measurements (Table 23).

Table 18. Interperiod Spearman correlation coefficients of simple anthropometrical parameters, somatotype components, PAI and Tanner stages, girls in *Italic*.

	10 vs. 11 yrs	**10 vs. 12 yrs**	**10 vs. 13 yrs**	**11 vs. 12 yrs**	**11 vs. 13 yrs**	**12 vs. 13 yrs**
Height	0.986 *0.987*	0.951 *0.957*	0.938 *0.912*	0.972 *0.974*	0.956 *0.931*	0.962 *0.978*
Body mass	0.952 *0.966*	0.905 *0.940*	0.912 *0.906*	0.954 *0.966*	0.940 *0.941*	0.957 *0.979*
BMI	0.886 *0.926*	0.828 *0.814*	0.847 *0.861*	0.928 *0.838*	0.913 *0.915*	0.943 *0.847*
Endomorphy	0.851 *0.947*	0.769 *0.889*	0.693 *0.894*	0.863 *0.914*	0.758 *0.866*	0.901 *0.890*
Mesomorphy	0.810 *0.845*	0.790 *0.873*	0.780 *0.829*	0.867 *0.854*	0.860 *0.819*	0.882 *0.912*
Ectomorphy	0.885 *0.892*	0.817 *0.861*	0.845 *0.970*	0.922 *0.917*	0.910 *0.874*	0.933 *0.943*
PAI	0.272 *0.581*	0.381 *0.252*	0.294 *0.406*	0.446 *0.495*	0.352 *0.491*	0.434 *0.505*
Tanner stage	0.490 *0.636*	0.508 *0.365*	0.314 *0.354*	0.662 *0.722*	0.484 *0.607*	0.683 *0.632*

BMI — body mass index;
PAI — physical activity index.

Table 19. Interperiod Spearman correlation coefficients of skinfold thicknesses at four timepoints, girls in *Italic*.

	10 vs. 11 yrs	**10 vs. 12 yrs**	**10 vs. 13 yrs**	**11 vs. 12 yrs**	**11 vs. 13 yrs**	**12 vs. 13 yrs**
Triceps	0.829 *0.923*	0.698 *0.848*	0.646 *0.860*	0.819 *0.883*	0.743 *0.815*	0.842 *0.859*
Subscapular	0.822 *0.950*	0.760 *0.873*	0.653 *0.916*	0.861 *0.910*	0.747 *0.901*	0.915 *0.911*
Biceps	0.759 *0.852*	0.633 *0.832*	0.585 *0.794*	0.781 *0.893*	0.709 *0.810*	0.822 *0.833*
Iliac crest	0.830 *0.946*	0.725 *0.892*	0.592 *0.867*	0.830 *0.910*	0.693 *0.844*	0.884 *0.907*
Supraspinale	0.789 *0.884*	0.691 *0.848*	0.691 *0.858*	0.782 *0.889*	0.688 *0.780*	0.824 *0.816*
Abdominal	0.854 *0.923*	0.697 *0.912*	0.591 *0.847*	0.847 *0.898*	0.746 *0.852*	0.878 *0.904*
Front thigh	0.858 *0.897*	0.771 *0.793*	0.695 *0.811*	0.884 *0.906*	0.712 *0.893*	0.860 *0.886*
Medial calf	0.850 *0.907*	0.821 *0.877*	0.709 *0.817*	0.844 *0.905*	0.733 *0.847*	0.829 *0.878*
Mid-axilla	0.848 *0.948*	0.698 *0.918*	0.630 *0.878*	0.815 *0.931*	0.645 *0.866*	0.819 *0.931*

Table 20. Interperiod Spearman correlation coefficients of girths at four time points, girls in *Italic*.

	10 vs. 11 yrs	**10 vs. 12 yrs**	**10 vs. 13 yrs**	**11 vs. 12 yrs**	**11 vs. 13 yrs**	**12 vs. 13 yrs**
Head	0.755 *0.863*	0.846 *0.884*	0.813 *0.847*	0.843 *0.887*	0.796 *0.913*	0.889 *0.883*
Neck	0.863 *0.908*	0.745 *0.846*	0.804 *0.833*	0.797 *0.904*	0.871 *0.853*	0.791 *0.876*
Arm relaxed	0.889 *0.944*	0.877 *0.908*	0.848 *0.878*	0.905 *0.946*	0.866 *0.905*	0.946 *0.952*
Arm flexed and tensed	0.921 *0.942*	0.881 *0.899*	0.860 *0.881*	0.933 *0.931*	0.905 *0.901*	0.944 *0.953*
Forearm	0.844 *0.944*	0.906 *0.844*	0.889 *0.877*	0.812 *0.878*	0.921 *0.921*	*0.949* *0.876*
Wrist	0.889 *0.914*	0.849 *0.858*	0.810 *0.870*	0.932 *0.922*	0.893 *0.905*	0.934 *0.941*
Chest	0.911 *0.950*	0.653 *0.911*	0.896 *0.839*	0.758 *0.951*	0.911 *0.896*	0.683 *0.935*
Waist	0.923 *0.957*	0.855 *0.885*	0.859 *0.887*	0.879 *0.928*	0.837 *0.914*	0.907 *0.919*

Table 20 (continued)

	10 vs. 11 yrs	**10 vs. 12 yrs**	**10 vs. 13 yrs**	**11 vs. 12 yrs**	**11 vs. 13 yrs**	**12 vs. 13 yrs**
Gluteal (hip)	0.954	0.896	0.919	0.883	0.921	0.860
	0.971	*0.822*	*0.905*	*0.833*	*0.922*	*0.831*
Thigh	0.924	0.827	0.905	0.838	0.919	0.812
	0.967	*0.909*	*0.908*	*0.925*	*0.925*	*0.921*
Mid-thigh	0.918	0.857	0.841	0.889	0.877	0.872
	0.951	*0.813*	*0.892*	*0.841*	*0.916*	*0.852*
Calf	0.959	0.788	0.909	0.833	0.935	0.831
	0.955	*0.913*	*0.906*	*0.940*	*0.939*	*0.949*
Ankle	0.926	0.893	0.866	0.931	0.862	0.910
	0.914	*0.855*	*0.842*	*0.870*	*0.850*	*0.865*

Table 21. Interperiod Spearman correlation coefficients of length at four time points, girls in *Italic.*

	10 vs. 11 yrs	**10 vs. 12 yrs**	**10 vs. 13 yrs**	**11 vs. 12 yrs**	**11 vs. 13 yrs**	**12 vs. 13 yrs**
Acromiale – radiale	0.961	0.886	0.588	0.934	0.613	0.585
	0.824	*0.819*	*0.601*	*0.685*	*0.570*	*0.553*
Radiale – stylion	0.875	0.709	0.851	0.836	0.948	0.817
	0.971	*0.910*	*0.799*	*0.927*	*0.798*	*0.829*
Midstylion-dactylion	0.781	0.347	0.595	0.445	0.643	0.552
	0.432	*0.457*	*0.426*	*0.844*	*0.749*	*0.650*
Iliospinale	0.950	0.915	0.923	0.974	0.964	0.958
	0.968	*0.925*	*0.266*	*0.967*	*0.263*	*0.320*
Trochanterion	0.947	0.914	0.920	0.940	0.942	0.948
	0.892	*0.815*	*0.809*	*0.918*	*0.900*	*0.898*
Trochanterion-tibiale laterale	0.814	0.801	0.792	0.848	0.823	0.866
	0.901	*0.828*	*0.477*	*0.870*	*0.486*	*0.515*
Tibiale-laterale	0.809	0.880	0.852	0.815	0.844	0.900
	0.842	*0.838*	*0.787*	0.865	*0.839*	*0.865*
Tibiale mediale-sphyrion tibiale	0.835	0.734	0.807	0.846	0.935	0.830
	0.900	*0.847*	*0.754*	*0.886*	*0.789*	*0.807*

Table 22. Interperiod Spearman correlation coefficients of breadths/lengths at four time points, girls in *Italic*.

	10 vs. 11 yrs	**10 vs. 12 yrs**	**10 vs. 13 yrs**	**11 vs. 12 yrs**	**11 vs. 13 yrs**	**12 vs. 13 yrs**
Biacromial	0.717 *0.803*	0.794 *0.815*	0.860 *0.789*	0.664 *0.678*	0.714 *0.622*	0.791 *0.961*
Biiliocristal	0.828 *0.883*	0.766 *0.758*	0.707 *0.691*	0.887 *0.881*	0.854 *0.776*	0.923 *0.829*
Foot length	0.972 *0.982*	0.949 *0.924*	0.798 *0.836*	0.978 *0.959*	0.783 *0.868*	0.803 *0.893*
Sitting height	0.896 *0.961*	0.813 *0.918*	0.857 *0.903*	0.849 *0.945*	0.848 *0.917*	0.927 *0.958*
Transverse chest	0.468 *0.945*	0.486 *0.899*	0.376 *0.880*	0.838 *0.955*	0.820 *0.929*	0.821 *0.936*
Anterior-posterior chest depth	0.804 *0.916*	0.788 *0.869*	0.700 *0.591*	0.867 *0.928*	0.387 *0.561*	0.897 *0.599*
Biepicondylar humerus	0.948 *0.942*	0.905 *0.868*	0.909 *0.876*	0.911 *0.902*	0.897 *0.890*	0.911 *0.874*
Biepicondylar femur	0.968 *0.959*	0.909 *0.894*	0.845 *0.879*	0.929 *0.911*	0.868 *0.887*	0.876 *0.929*

Table 23. Mean (±SD) body impedance and impedance indeces and interperiod correlations in boys, girls in *Italic.*

	Interperiod correlations		
	First measurement	**Second measurement**	**Third measurement**
Body impedance (Ω)			
Second measurement	0.904 *0.951*		
Third measurement	0.900 *0.874*	0.911 *0.921*	
Fourth measurement	0.841 *0.795*	0.877 *0.886*	0.942 *0.914*
Impedance index (cm ^{2}/Ω)			
Second measurement	0.926 *0.914*		
Third measurement	0.904 *0.864*	0.916 *0.907*	
Fourth measurement	0.887 *0.777*	0.871 *0.874*	0.915 *0.900*

5.3. Longitudinal reproducibility of different anthropometrical and body compositional parameters during puberty (Study II)

The reproducibility of body height (r=0.995–0.999), body mass (r=0.990–0.999) and BMI (r=0.969–0.999) was very high in boys and girls (Table 24). TE for height was between 0.3–0.5 cm in boys and between 0.1–0.5 cm in girls, for body mass between 0.4–0.8 kg in boys and 0.1–0.5 kg in girls, and for BMI between 0.2–0.3 in boys and between 0.1–0.3 in girls. CV was lower in girls compared with boys — body height: 0.2–0.3% for boys and 0.1–0.3% for girls, body mass: 1.0–1.9% for boys and 0.3–1.5% for girls and BMI: 1.1–1.7% for boys and 0.6–1.8% for girls.

The mean skinfold thicknesses and several reproducibility parameters (TE, CV, ICC) are presented in Table 25. Our results indicated that the ICCs were between r=0.723 (*biceps*) and r=0.999 (*triceps* and *subscapular*) in boys and between r=0.886 (*supraspinale*) and r=0.999 (*iliac crest, supraspinale, front thigh*) in girls. The ICCs were highest during the second year of measurement. TEs were between 0.2–1.8 mm in boys and between 0.1–1.8 mm in girls. The TEs were lowest during the second year of measurement. The TE for sum of skinfolds was between 2.2–4.3 mm in boys and between 1.0–5.7 mm in girls. The distribution of CVs was high in both sexes and highly dependent on the anatomical location of the skinfold: 0.1–18.1% in boys and 1.1–18.9% in girls.

The mean girth parameters and their reproducibility are presented in Tables 26 (boys) and 27 (girls). In boys, the ICCs were between r=0.830 (*forearm*) and r=0.999 (*calf*) and between r=0.904 (*wrist*) and r=0.999 (*gluteal, calf*) in girls. The highest ICCs ocurred during the second year of measurement in boys and girls. The TEs in boys and girls were between 0.1–1.0 cm and 0.1–0.9 cm in boys and girls, respectively. The CVs were between 0.3–3.2% in boys and between 0.3–2.6% in girls.

The mean length parameters and their reproducibility are presented in Table 28. The ICCs were about the same in boys (r=0.859–0.998) and girls (r=0.879–0.999). The TEs were between 0.1–1.2 cm in boys and between 0.1–1.1 cm in girls. The TEs were the smallest during the second year of measurement and largest during the first year of measurement. The distribution of the CVs of length parameters was about the same as in girth parameters: 0.2–4.1% for boys and 0.2–3.4% for girls.

The reproducibility of breadth/length parameters was very high in boys (r=0.942–0.999) and slightly lower in girls (r=0.843–1.000) (Table 29). The TEs in boys were between 0.1–0.8 cm and between 0.1–0.7 cm in girls. The TEs were the smallest during the second year of measurement. TE was stable and very small (0.1 cm) in both boys and girls throughout the three years of measurements in humerus and femur sites. Additionally, the TE was small (0.1 cm) in foot length in girls. The CV was rather small in both boys (0.4–3.2%) and girls (0.3–3.3%).

Table 24. Mean (±SD) physical characteristics and reproducibility in boys and girls.

	FIRST MEASUREMENT					SECOND MEASUREMENT					THIRD MEASUREMENT				
	TRIAL1	**TRIAL2**	**TE**	**CV**	**ICC**	**TRIAL1**	**TRIAL2**	**TE**	**CV**	**ICC**	**TRIAL1**	**TRIAL2**	**TE**	**CV**	**ICC**
BOYS															
Age (years)	10.2±0.8					11.2±0.8					12.1±0.8				
Height (cm)	143.7±6.7	144.1±6.7	0.5	0.3	0.995	149.4±7.3	149.5±7.4	0.3	0.2	0.999	156.4±7.9	157.5±6.9	0.3	0.2	0.998
Body mass (kg)	36.3±6.2	36.6±5.9	0.7	1.9	0.990	40.2±7.2	40.5±7.2	0.4	1.0	0.997	47.0±10.0	48.4±10.2	0.8	1.7	0.997
BMI (kg/m^2)	17.5±2.0	17.5±1.9	0.3	1.7	0.969	17.9±2.1	18.0±2.3	0.2	1.1	0.993	19.1±3.1	19.1±3.1	0.3	1.6	0.994
GIRLS															
Age (years)	9.6±0.6					10.7±0.6					11.6±0.6				
Height (cm)	140.4±7.4	140.5±7.4	0.4	0.3	0.997	146.3±8.1	146.4±8.4	0.1	0.1	0.999	152.3±8.1	152.9±8.3	0.5	0.3	0.996
Body mass(kg)	32.7±6.0	32.6±5.9	0.5	1.5	0.993	36.0±7.3	35.6±7.3	0.1	0.3	0.999	41.4±9.4	42.2±9.5	0.5	1.2	0.998
BMI (kg/m^2)	16.4±1.9	16.4±1.9	0.3	1.8	0.981	16.4±1.9	16.4±1.9	0.1	0.6	0.999	17.7±2.8	17.8±2.8	0.2	1.1	0.995

BMI — body mass index;
TE — technical error;
CV — coefficient of variation;
ICC — intraclass correlation.

Table 25. Mean (±SD) results and reproducibility of skinfold thicknesses (mm) in children.

	FIRST MEASUREMENT					SECOND MEASUREMENT					THIRD MEASUREMENT				
	TRIAL1	TRIAL2	TE	CV	ICC	TRIAL1	TRIAL2	TE	CV	ICC	TRIAL1	TRIAL2	TE	CV	ICC
BOYS															
Triceps	10.2±3.1	10.6±3.7	0.8	7.7	0.979	11.6±4.5	11.9±4.6	0.4	3.4	0.999	11.8±5.9	13.2±6.1	1.0	8.0	0.976
Subscapular	8.2±4.3	8.3±4.6	0.5	6.1	0.991	10.0±5.1	10.2±5.3	0.2	2.0	0.999	10.6±6.9	11.3±6.7	1.2	11.0	0.970
Biceps	7.6±2.1	6.8±2.2	1.3	18.1	0.723	7.9±3.2	7.9±3.5	0.7	8.9	0.956	7.4±3.4	8.1±3.5	0.8	10.3	0.945
Iliac crest	9.9±5.8	10.0±5.9	1.8	18.1	0.908	12.2±6.7	12.4±7.0	0.6	4.9	0.992	14.9±8.7	15.1±9.2	1.1	7.3	0.989
Supraspinale	5.7±3.2	5.7±3.0	0.6	10.5	0.959	7.5±4.1	7.6±4.4	0.8	10.6	0.962	8.9±6.6	9.9±7.2	0.7	7.4	0.986
Abdominal	9.6±5.9	9.5±6.1	0.5	0.1	0.994	12.3±7.6	12.7±8.3	0.7	5.6	0.996	15.0±10.5	17.3±11.1	1.3	8.0	0.988
Front thigh	16.9±4.8	16.7±5.5	1.4	8.3	0.935	19.6±6.8	19.3±7.1	0.7	3.6	0.989	18.7±6.9	18.6±7.1	1.3	7.0	0.973
Medial calf	12.9±3.9	12.9±4.9	1.6	12.4	0.885	15.0±5.1	14.9±4.9	0.6	4.0	0.988	14.2±6.0	14.3±4.9	1.4	9.8	0.952
Mid-axilla	5.8±2.2	5.9±2.1	0.4	6.8	0.965	6.8±3.1	6.9±3.1	0.3	4.4	0.991	7.6±4.5	8.2±4.5	0.7	8.9	0.978
Sum of skinfolds	86.4±32.5	86.4±35.6	4.3	5.0	0.988	102.7±43.0	103.9±45.2	2.6	2.5	0.997	107.2±55.7	109.9±53.3	2.2	2.0	0.998
GIRLS															
Triceps	11.1±2.9	11.0±2.8	0.8	8.0	0.922	11.6±4.1	11.6±4.1	0.3	2.6	0.966	12.4±5.0	12.7±5.0	0.3	2.4	0.996
Subscapular	7.8±3.7	7.8±4.0	0.8	10.3	0.952	8.5±4.2	8.5±4.1	0.2	2.4	0.998	10.2±6.5	10.5±6.6	0.3	2.9	0.997
Biceps	8.4±3.5	7.4±3.3	1.0	12.7	0.948	7.0±2.2	6.9±2.3	0.2	2.9	0.990	7.3±3.4	7.5±3.5	0.6	8.1	0.964
Iliac crest	7.9±3.3	8.3±3.7	0.9	11.1	0.944	8.4±5.0	8.5±5.0	0.2	2.4	0.999	11.2±8.2	11.2±8.3	0.8	7.1	0.992
Supraspinale	6.2±2.8	6.0±2.6	1.1	18.0	0.886	6.1±3.4	6.2±3.3	0.1	1.6	0.999	8.1±5.8	8.6±6.2	0.7	8.4	0.989
Abdominal	10.1±5.5	8.9±5.1	1.8	18.9	0.908	9.3±4.9	9.3±4.9	0.4	4.3	0.995	12.1±7.1	12.8±7.5	0.6	4.8	0.995
Front thigh	17.3±4.6	17.6±4.5	0.9	5.2	0.959	18.5±5.9	18.5±6.0	0.2	1.1	0.999	18.6±7.8	19.8±7.4	1.4	7.3	0.966
Medial calf	12.9±5.1	13.3±3.7	1.7	13.0	0.892	13.6±4.1	13.9±4.3	1.4	10.2	0.986	14.0±5.9	14.6±4.8	1.3	9.1	0.959
Mid-axilla	5.9±2.3	5.8±2.2	0.6	10.3	0.926	5.9±2.5	5.9±2.5	0.2	3.4	0.992	6.7±3.8	6.9±3.7	0.3	4.4	0.994
Sum of skinfolds	86.8±28.7	85.9±28.5	5.1	5.9	0.966	92.9±35.1	93.0±34.9	1.0	1.1	0.999	105.9±52.6	113.5±51.8	5.7	5.2	0.987

TE — technical error;
CV — coefficient of variation;
ICC — intraclass correlation.

Table 26. Mean (±SD) results and reproducibility of girths (cm) in boys.

	FIRST MEASUREMENT					SECOND MEASUREMENT					THIRD MEASUREMENT				
	TRIAL1	TRIAL2	TE	CV	ICC	TRIAL1	TRIAL2	TE	CV	ICC	TRIAL1	TRIAL2	TE	CV	ICC
Head	53.0±1.6	53.6±1.2	0.7	1.3	0.877	53.6±1.3	53.6±1.3	0.2	0.4	0.974	54.4±1.5	54.5±1.4	0.2	0.4	0.978
Neck	28.1±1.3	28.1±1.2	0.4	1.4	0.891	28.8±1.5	28.8±1.5	0.1	0.3	0.992	29.9±1.7	30.1±1.9	0.2	0.7	0.996
Arm relaxed	20.2±1.8	20.2±1.9	0.5	2.5	0.916	21.0±2.0	21.2±2.0	0.3	1.4	0.982	22.5±2.8	23.2±2.6	0.2	0.9	0.994
Arm flexed and tensed	21.4±2.2	21.9±2.0	0.7	3.2	0.932	23.0±2.1	23.2±2.1	0.7	3.0	0.992	24.2±2.7	24.8±2.4	0.3	1.2	0.979
Forearm	20.0±1.6	20.1±1.4	0.6	3.0	0.830	20.8±1.5	20.9±1.5	0.1	0.5	0.996	21.9±1.9	22.3±1.7	0.1	0.5	0.992
Wrist	13.6±0.9	13.8±0.8	0.2	1.5	0.969	14.1±1.0	14.2±1.1	0.1	0.7	0.995	14.7±1.2	14.9±1.3	0.1	0.7	0.995
Chest	62.8±5.2	69.5±5.5	0.9	1.4	0.979	70.9±5.6	71.2±5.7	0.4	0.6	0.994	75.4±7.6	76.5±7.4	1.0	1.3	0.981
Waist	60.2±5.1	61.0±5.2	1.0	1.7	0.969	62.6±5.4	63.1±5.8	0.7	1.1	0.986	65.6±7.9	67.0±7.7	0.9	1.4	0.985
Gluteal (hip)	71.9±6.2	72.9±6.1	1.0	1.4	0.985	76.2±6.5	76.5±6.6	0.5	0.7	0.994	79.4±8.4	80.7±8.3	0.8	1.0	0.990
Thigh	42.6±4.6	43.0±4.8	0.8	1.9	0.975	45.1±4.8	45.2±4.9	0.3	0.7	0.997	49.5±9.6	50.9±9.8	0.7	1.4	0.995
Mid-thigh	39.1±4.2	39.8±3.9	0.8	2.0	0.978	41.8±4.3	41.8±4.9	1.0	2.4	0.963	45.0±5.2	45.9±4.9	0.5	1.1	0.991
Calf	28.5±2.8	29.0±2.8	0.5	1.7	0.971	30.2±2.9	30.2±3.1	0.1	0.3	0.998	32.8±4.5	32.9±4.7	0.2	0.6	0.999
Ankle	18.7±1.7	19.0±1.7	0.3	1.6	0.973	20.0±1.7	20.1±1.7	0.1	0.5	0.994	22.0±3.1	22.4±3.2	0.5	2.3	0.979

TE — technical error;
CV — coefficient of variation;
ICC — intraclass correlation.

Table 27. Mean (±SD) results and reproducibility of girths (cm) in girls.

	FIRST MEASUREMENT					SECOND MEASUREMENT					THIRD MEASUREMENT				
	TRIAL1	TRIAL2	TE	CV	ICC	TRIAL1	TRIAL2	TE	CV	ICC	TRIAL1	TRIAL2	TE	CV	ICC
Head	52.2±1.6	52.3±1.5	0.3	0.6	0.975	52.7±1.7	52.7±1.7	0.2	0.4	0.992	53.4±1.7	53.3±1.5	0.5	0.9	0.918
Neck	26.5±1.3	26.7±1.4	0.4	1.5	0.926	26.8±1.6	26.8±1.6	0.1	0.4	0.995	28.0±1.8	28.3±2.0	0.5	1.8	0.940
Arm relaxed	19.1±2.0	19.3±1.9	0.5	2.6	0.924	19.7±2.3	19.7±2.2	0.1	0.5	0.998	21.2±2.8	21.4±2.6	0.1	0.5	0.997
Arm flexed and tensed	20.3±2.2	20.6±1.9	0.4	2.0	0.975	21.2±2.3	21.1±2.2	0.2	0.9	0.994	22.4±2.8	22.6±2.8	0.4	1.8	0.984
Forearm	18.8±1.4	18.8±1.3	0.3	1.6	0.952	19.2±1.5	19.3±1.4	0.1	0.5	0.996	20.2±2.0	20.5±1.6	0.5	2.5	0.944
Wrist	12.8±0.8	12.8±0.8	0.2	1.6	0.964	13.0±0.8	13.0±0.8	0.1	0.8	0.992	13.5±0.8	13.6±0.9	0.1	0.7	0.991
Chest	64.7±5.0	65.1±5.4	0.8	1.2	0.979	66.8±6.8	66.9±6.7	0.8	1.2	0.997	72.3±8.0	73.0±8.6	0.6	0.8	0.997
Waist	55.2±4.1	55.3±4.2	0.9	1.6	0.945	56.2±4.5	56.5±4.2	0.4	0.7	0.993	59.4±5.3	59.9±5.0	0.5	0.8	0.993
Gluteal (hip)	69.8±5.8	70.5±5.9	0.7	1.0	0.991	73.2±6.9	73.2±6.6	0.3	0.4	0.999	78.7±8.3	79.4±8.3	0.3	0.4	0.999
Thigh	41.3±4.2	41.5±4.1	0.6	1.4	0.981	42.9±4.4	42.9±4.4	0.2	0.5	0.998	46.1±5.6	46.5±5.6	0.5	1.1	0.992
Mid-thigh	38.2±3.6	38.7±3.7	0.9	2.3	0.953	39.5±3.6	39.6±3.6	0.3	0.8	0.998	43.0±5.4	43.6±5.1	0.7	1.6	0.984
Calf	27.9±2.7	28.2±2.6	0.3	1.1	0.989	29.1±2.8	29.0±2.8	0.1	0.3	0.999	30.7±3.2	30.9±3.3	0.2	0.6	0.996
Ankle	18.0±1.4	18.1±1.4	0.2	1.1	0.977	18.7±1.6	18.6±1.7	0.2	1.1	0.986	19.8±1.4	19.7±1.6	0.3	1.5	0.992

TE — technical error;
CV — coefficient of variation;
ICC — intraclass correlation.

Table 28. Mean (±SD) results and reproducibility of lengths (cm) parameters in children.

	FIRST MEASUREMENT					SECOND MEASUREMENT					THIRD MEASUREMENT				
	TRIAL1	TRIAL2	TE	CV	ICC	TRIAL1	TRIAL2	TE	CV	ICC	TRIAL1	TRIAL2	TE	CV	ICC
BOYS															
Acromiale-radiale	30.2±1.8	30.6±1.9	0.5	1.6	0.962	32.3±2.2	32.3±2.3	0.1	0.3	0.997	32.5±3.9	32.7±4.2	0.4	1.2	0.990
Radiale-stylion	23.1±1.9	23.0±1.3	0.9	3.9	0.961	23.8±1.6	23.9±1.6	0.2	0.8	0.986	25.1±2.6	25.7±2.6	0.3	1.2	0.983
Midstylion-dactylion	17.3±1.1	16.6±0.9	0.7	4.1	0.899	17.1±1.0	17.2±1.0	0.2	1.2	0.952	17.8±1.9	18.3±2.0	0.4	2.2	0.970
Iliospinale	83.4±4.2	83.5±4.3	1.1	1.3	0.936	85.5±5.0	85.5±5.1	0.2	0.2	0.998	85.8±17.7	85.2±19.4	0.5	0.6	0.998
Trochanterion	76.2±4.5	76.1±4.0	1.2	1.6	0.923	78.8±4.5	78.8±4.7	0.4	0.5	0.994	82.7±5.1	83.4±4.8	0.7	0.8	0.980
Trochanterion-tibiale laterale	38.9±2.9	38.9±2.5	1.0	2.6	0.859	40.4±2.7	40.5±2.8	0.4	1.0	0.977	44.7±10.0	45.6±10.5	0.6	1.3	0.997
Tibiale laterale	37.0±2.0	36.7±2.1	0.7	1.9	0.891	38.8±2.2	38.6±2.2	0.3	0.8	0.981	40.6±2.4	40.5±2.5	0.8	2.0	0.861
Tibiale mediale-sphyrion tibiale	28.9±2.2	29.7±2.0	0.8	2.7	0.954	31.8±2.1	31.9±2.2	0.1	0.3	0.996	33.6±2.6	33.9±2.6	0.4	1.2	0.974
GIRLS															
Acromiale-radiale	29.6±2.0	29.8±1.9	0.2	0.7	0.991	31.4±2.2	31.4±2.2	0.1	0.3	0.999	32.6±2.4	32.7±2.5	0.3	0.9	0.989
Radiale-stylion	22.1±1.3	22.2±1.3	0.3	1.4	0.934	23.1±1.7	23.1±1.7	0.1	0.4	0.999	24.1±1.6	24.3±1.6	0.1	0.4	0.996
Midstylion-dactylion	16.5±1.3	16.1±1.2	0.6	3.4	0.879	16.6±1.4	16.6±1.4	0.1	0.6	0.995	17.0±1.4	17.2±1.5	0.3	1.8	0.949
Iliospinale	81.9±4.9	81.4±4.5	1.0	1.2	0.961	83.3±5.3	83.2±5.3	0.2	0.2	0.999	87.4±5.1	87.8±5.4	0.4	0.5	0.996
Trochanterion	75.5±5.5	74.9±4.6	0.2	0.3	0.946	77.6±4.8	77.6±5.0	0.3	0.4	0.996	81.0±4.8	81.2±5.0	0.3	0.4	0.997
Trochanterion-tibiale laterale	39.0±3.4	38.8±2.7	1.1	2.8	0.897	39.7±2.9	39.7±3.2	0.5	1.3	0.979	41.5±2.8	41.6±3.0	0.4	1.0	0.983
Tibiale laterale	36.6±2.5	36.2±2.4	0.6	1.6	0.950	38.2±2.2	38.3±2.0	0.3	0.8	0.985	39.6±2.3	39.6±2.2	0.5	1.3	0.959
Tibiale mediale sphyrion tibiale	28.0±1.8	28.7±1.9	0.6	2.1	0.946	31.2±2.3	31.3±2.3	0.1	0.3	0.996	32.8±2.4	33.0±2.4	0.5	1.5	0.959

TE — technical error;
CV — coefficient of variation;
ICC — intraclass correlation.

Table 29. Mean (±SD) results and reproducibility of breadths/lengths (cm) parameters in children.

	FIRST MEASUREMENT					SECOND MEASUREMENT					THIRD MEASUREMENT				
	TRIAL1	TRIAL2	TE	CV	ICC	TRIAL1	TRIAL2	TE	CV	ICC	TRIAL1	TRIAL2	TE	CV	ICC
BOYS															
Biacromial	31.5±2.0	31.9±1.9	0.4	1.3	0.974	33.2±1.9	33.3±1.9	0.2	0.6	0.985	34.7±2.5	34.9±2.4	0.3	0.9	0.983
Biiliocristal	21.6±1.5	22.0±1.9	0.7	3.2	0.955	23.4±1.8	23.5±1.8	0.1	0.4	0.998	25.2 ±2.9	25.7±2.9	0.2	0.8	0.995
Foot length	22.6±1.5	22.6±1.5	0.1	0.4	0.996	23.7±1.6	23.7±1.6	0.1	0.4	0.999	24.7±1.6	25.0±1.8	0.2	0.8	0.942
Sitting height	76.0±3.2	76.0±3.6	0.8	1.1	0.954	78.3±3.9	78.3±4.1	0.4	0.5	0.989	80.4±4.0	80.7±4.0	0.1	0.1	0.992
Trasverse chest	21.8±1.6	21.9±1.7	0.3	1.4	0.974	22.9±1.8	23.0±1.8	0.1	0.4	0.997	24.0±2.3	24.1±2.2	0.1	0.4	0.986
Anterior-posterior chest depth	14.9±1.1	15.1±1.3	0.3	2.0	0.945	15.7±1.2	15.6±1.2	0.1	0.6	0.988	16.5±1.7	16.8±1.8	0.2	0.1	0.996
Biepicondylar humerus	6.1±0.4	6.1±0.4	0.1	1.6	0.950	6.2±0.5	6.2±0.5	0.1	1.6	0.995	6.6±0.4	6.7±0.4	0.1	1.5	0.926
Biepicondylar femur	8.9±0.5	8.9±0.5	0.1	1.1	0.978	9.1±0.5	9.1±0.5	0.1	1.1	0.997	9.7±0.6	9.8±0.5	0.1	1.0	0.994
GIRLS															
Biacromial	30.3±1.8	30.3±1.9	0.3	1.0	0.972	31.4±2.7	31.4±2.7	0.1	0.3	0.998	33.2±2.2	33.5±2.2	0.2	0.6	0.990
Biiliocristal	21.0±1.4	21.4±1.6	0.7	3.3	0.843	22.9±1.7	22.9±1.6	0.1	0.4	0.998	24.9±1.7	24.9±2.0	0.4	1.6	0.957
Foot length	21.9±1.4	21.9±1.4	0.1	0.5	0.991	22.8±1.5	22.8±1.5	0.1	0.4	0.999	23.5±1.4	23.4±1.4	0.1	0.4	0.992
Sitting height	73.8±3.8	73.7±4.1	0.6	0.8	0.979	76.3±4.2	76.3±4.2	0.2	0.3	0.998	78.4±4.1	78.6±4.3	0.2	0.3	0.997
Trasverse chest	20.5±1.4	20.5±1.4	0.2	1.0	0.978	21.5±1.6	21.5±1.6	0.1	0.5	0.999	22.7±1.9	22.7±2.0	0.2	0.9	0.992
Anterior-posterior chest depth	13.9±1.0	14.3±1.0	0.4	2.8	0.960	14.6±1.3	14.6±1.3	0.1	0.7	0.996	15.5±1.4	15.7±1.6	0.3	1.9	0.978
Biepicondylar humerus	5.8±0.3	5.8±0.3	0.1	1.7	0.932	5.9±0.4	5.9±0.4	0.1	1.7	0.995	6.2±0.3	6.2±0.4	0.1	1.6	0.983
Biepicondylar femur	8.4±0.5	8.3±0.5	0.1	1.2	0.983	8.4±0.5	8.4±0.5	0	0	1.000	8.9±0.5	8.9±0.5	0.1	1.1	0.992

TE — technical error;
CV — coefficient of variation;
ICC — intraclass correlation.

5.4. Relationships between different anthropometrical parameters, somatotype, bioelectrical impedance and body composition measured by dual-energy X-ray absorptiometry in pubertal children (Study III)

Table 30 summarizes the mean auxological, somatotype, body impedance and FM measures (by DXA) in boys (n=26) and girls (n=27). No difference was found in body height. Body mass and BMI were higher in boys ($p<0.05$). Boys were more mesomorphic and girls more ectomorphic. Body impedance was higher in girls and impedance index in boys. DXA analysis indicated that there were no significant differences between sexes in the total body fat mass and separately in arms, legs or trunk fat mass ($p>0.05$).

Table 30. Auxology, somatotypes, body impedance and fat mass measured by DXA.

	BOYS	**GIRLS**
Age (yrs)	12.2±0.7	11.8±0.7*
Height (cm)	156.5±7.2	152.8±8.5
Body mass (kg)	45.2±8.3	39.4±6.3*
BMI	18.4±2.5	16.8±1.5*
Endomorphy	2.4±1.5	2.4±1.0
Mesomorphy	4.2±1.0	3.3±0.8*
Ectomorphy	3.7±1.3	4.4±1.0*
Bioelectrical impedance analysis		
Body impedance(Ω)	567.8±55.4	622.5±55.7*
Impedance index ($cm^2/Ω$)	44.2±8.2	37.8±6.3*
Dual-energy X-ray absorptiometry		
Total body fat (g)	7938.7±5005.0	7544.6±2958.9
Arms fat (g)	889.5±690.3	827.6±499.9
Legs fat (g)	3461.2±1847.7	3379.5±1165.4
Trunk fat (g)	2913.4±2287.5	2695.0±1202.0

*significantly different from girls ($p<0.05$–0.01).
BMI — body mass index

Mean anthropometrical parameters (skinfolds, girths, lengths, breadths/ lengths) are presented in Table 31. There were no any significant differences between sexes in the measured skinfold thicknesses. Most of the measured girths were higher in boys compared with girls. Four length parameters were higher in boys. Most of the breadth/length parameters were higher in boys.

Table 31. Mean (±SD) skinfolds, girths, lengths and breadths/lengths parameters in boys and girls.

	BOYS	GIRLS
Skinfolds		
Triceps	9.8±4.5	10.7±3.8
Subscapular	8.4±5.7	8.2±3.1
Biceps	6.4±2.7	7.0±2.5
Iliac crest	11.4±8.3	9.6±4.6
Supraspinale	6.9±5.7	5.8±2.9
Abdominal	12.8±10.0	9.6±4.3
Front thigh	16.9±6.1	17.5±5.5
Medial calf	12.7±5.2	12.8±4.4
Mid-axilla	6.8±4.5	5.8±1.9
Sum of skinfolds	92.4±49.5	88.5±30.9
Girths		
Head	54.1±1.3	53.3±1.4*
Neck	29.9±1.6	27.8±1.4*
Arm (relaxed)	22.1±2.3	20.6±1.5*
Arm (flexed and tensed)	24.0±2.2	21.9±1.8*
Forearm (maximum)	21.8±1.5	20.2±1.2*
Wrist (distal styloids)	14.5±1.2	13.7±0.7*
Chest (mesosternale)	74.0±6.3	70.8±5.2*
Waist (minimum)	64.1±6.3	57.6±3.7*
Gluteal (hips)	78.3±6.5	77.5±5.7
Thigh (1 cm gluteal)	46.4±4.8	44.7±3.6
Thigh (mid tro-tib-lat)	43.7±4.1	41.9±3.4
Calf (maximum)	31.2±2.6	29.8±2.4*
Ankle (minimum)	20.8±1.6	19.5±1.2*
Lengths		
Acromiale-radiale	33.6±1.7	32.7±2.2
Radiale-stylion	25.1±1.5	24.1±1.4*
Midstylion-dactylion	17.6±1.0	16.9±1.3
Iliospinale	90.4±4.5	87.2±5.4*
Trochanterion	83.3±4.3	80.7±5.1
Trochanterion-tibiale laterale	43.1±2.4	41.4±2.9*
Tibiale laterale	40.2±2.3	39.0±2.4
Tibiale mediale-sphyrion tibiale	33.3±2.0	32.4±2.4
Breadths/lengths		
Biacromial	35.2±1.9	33.4±3.0
Biiliocristal	24.7±1.7	24.6±1.8
Foot length	24.5±1.3	23.2±1.3*
Sitting height	80.0±3.9	79.1±4.2
Trasverse chest	23.5±1.8	22.3±1.4*
Anterior-posterior chest depth	16.4±1.4	15.2±1.3*
Biepicondylar humerus	6.7±0.4	6.2±0.3*
Biepicondylar femur	9.6±0.5	8.8±0.5*

* significantly different from girls ($p<0.05–0.01$).

The results from multiple regression analysis showed no significant effect of skinfold thicknesses on body impedance or impedance index (Table 32). In contrast, girth parameters strongly influenced both body impedance and impedance index. Impedance index was more influenced by girth than body impedance (75–77% and 50–58%, respectively; R^2x100). Surprisingly, there was no significant association between body impedance and the length of the body. In girls, impedance index was highly influenced by the length parameters (81%) compared with boys (50%). Different breadth/length parameters significantly influenced both body impedance and impedance index, while from the somatotype components only mesomorphy influenced body impedance in boys (35%).

Table 32. Prediction of body impedance at 50 KHz and impedance index from anthropometrical parameters and somatotypes in boys and girls.

	SEX	ANTHROPO-METRICAL PARAMETERS	CONSTANT	R^2	SEE	p
Body impedance (Ω)						
Skinfold	Boys	–	–	–	–	–
	Girls	–	–	–	–	–
Girth	Boys	wrist	1117.1	0.58	36.9	<0.001
	Girls	calf gluteal	854.8	0.50	41.1	<0.001
Length	Boys	–	–	–	–	–
	Girls	–	–	–	–	–
Breadth/length	Boys	femur	1348.6	0.49	40.7	<0.001
	Girls	anterior-posterior chest	923.0	0.21	50.6	<0.05
Somatotype	Boys	mesomorphy	717.9	0.35	45.8	<0.004
	Girls	–	–	–	–	–
Impedance index (cm^2/Ω)						
Skinfold	Boys	–	–	–	–	–
	Girls	–	–	–	–	–
Girth	Boys	wrist	–42.6	0.75	4.2	<0.001
	Girls	wrist calf	–59.2	0.77	3.2	<0.001
Length	Boys	iliospinale	–75.1	0.50	5.9	<0.001
	Girls	iliospinale tibiale mediale sphyrion tibiale	–50.0	0.81	2.9	<0.001
Breadth/length	Boys	sitting height	–110.7	0.86	3.1	<0.001
	Girls	biacromial	–39.2	0.70	3.5	<0.001
Somatotype	Boys	–	–	–	–	–
	Girls	–	–	–	–	–

SEE — standard error of estimates

Body FM measured by DXA was highly associated with the *supraspinale* and *iliac crest* skinfold thicknesses in boys (92%; Table 33). Abdominal skinfold thickness characterized total body fat mass by 59% in girls. Thigh girth in boys and thigh and neck girths in girls characterized total body mass by 81% and 83%, respectively. The influence of lengths and breaths/lengths on the total fat mass was significant but relatively low (25–49%). Only endomorphy characterized total fat mass by 88% in boys and 52% in girls. The influence of specific anthropometrical parameters to the trunk fat mass is presented in Table 33. The main skinfold thicknesses were the same as on the total body fat mass and their influence to the trunk body fat are also about the same (92% and 62%, respectively, in boys and girls). Waist and gluteal girth influenced the trunk fat mass of the total variance by 68–79%.

Table 33. Prediction of total body and trunk fat mass measured by DXA from corresponding anthropometrical parameters and somatotypes in boys and girls.

	SEX	ANTHROPO-METRICAL PARAMETERS	CONSTANT	R^2	SEE	p
Total body fat mass (g)						
Skinfold	Boys	supraspinale iliac crest	1642.7	0.92	1452.7	<0.001
	Girls	abdominal	2479.4	0.59	1932.9	<0.001
Girth	Boys	thigh	–35356.0	0.81	2219.0	<0.001
	Girls	thigh neck	–12815.1	0.83	1273.0	<0.02
Length	Boys	–	–	–	–	–
	Girls	trochanterion	–15561.0	0.25	2618.4	<0.01
Breadth/length	Boys	transverse chest	–38048.7	0.49	3650.0	<0.001
	Girls	trasverse chest	–22045.9	0.43	2331.6	<0.001
Somatotype	Boys	endomorphy	527.8	0.88	1800.0	<0.001
	Girls	endomorphy	2268.0	0.52	2087.7	<0.001
Trunk fat mass (g)						
Skinfold	Boys	supraspinale	259.1	0.92	676.6	<0.001
	Girls	abdominal	592.7	0.62	760.0	<0.001
Girth	Boys	waist	–17590.2	0.79	1074.1	<0.001
	Girls	gluteal	–10787.8	0.68	689.7	<0.001
Length	Boys	–	–	–	–	–
	Girls	–	–	–	–	–
Breadth/length	Boys	transverse chest	–19404.0	0.55	1563.0	<0.001
	Girls	transverse chest anterior-posterior chest depth	–10867.7	0.49	895.3	<0.001

SEE — standard error of estimates

The specific breadth/length parameters influenced trunk fat mass by 49–55%. The skinfold thicknesses measured on the extremities (arms and legs) characterized fat mass measured by DXA better in boys compared with girls (Table 34). The thigh girth was a good predictor of the legs fat mass both in boys and girls (77–81% of the total variance). Length and breadth/length parameters were poor predictors of fat mass.

Table 34. Prediction of arms and legs fat mass from corresponding anthropometrical parameters in boys and girls.

	SEX	ANTHROPO-METRICAL PARAMETERS	CONSTANT	R^2	SEE	p
Arms fat mass						
Skinfolds	Boys	biceps	–310.6	0.54	477.7	<0.001
	Girls	triceps	35.0	0.33	418.1	<0.002
Girth	Boys	arm relaxed wrist	–4477.8	0.72	378.2	<0.001
	Girls	arm relaxed	–3126.0	0.32	411.4	<0.001
Length	Boys	–	–	–	–	–
	Girls	–	–	–	–	–
Breath/length	Boys	–	–	–	–	–
	Girls	–	–	–	–	–
Legs fat mass						
Skinfold	Boys	front thigh medial calf	–10007.0	0.81	834.6	<0.001
	Girls	front thigh	741.1	0.51	833.0	<0.001
Girth	Boys	thigh	–12498.0	0.81	824.6	<0.001
	Girls	thigh	–9390.9	0.77	569.0	<0.001
Length	Boys	–	–	–	–	–
	Girls	trochanterion	–7151.9	0.33	972.7	<0.002
Breath/length	Boys	–	–	–	–	–
	Girls	femur	–11814.4	0.45	883.6	<0.002

SEE — standard error of estimates

5.5. Relationships between bioelectric impedance and subcutaneous adipose tissue thickness measured by LIPOMETER and skinfold calipers in children (Study IV)

Physical characteristics of the children (n=96) — boys (n=52) and girls (n=44) in separately — are presented in Table 7. There were no significant differences between boys and girls in the main anthropometrical parameters (body height, body mass and BMI) or the level of physical activity (PAI: in boys 11.7±1.6 and girls 11.8±1.3). Mean subcutaneous adipose tissue thicknesses measured by skinfold caliper and LIPOMETER are presented in Table 35. There were no significant differences between boys and girls in subcutaneous adipose tissue

Table 35. The subcutaneous adipose tissue thickness (mm) measured by skinfold caliper and LIPOMETER in children.

Parameter	Boys	Girls	Total
Skinfold caliper			
Triceps	11.5±3.6	12.1±4.4	11.8±4.0
Subscapular	9.3±4.3	9.7±5.8	9.5±5.0
Biceps	7.2±2.8	7.9±3.7	7.6±3.2
Iliac crest	11.1±6.1	10.4±6.2	10.8±6.1
Supraspinale	6.8±3.5	7.1±4.7	6.9±4.0
Abdominal	11.7±6.4	10.6±6.2	11.2±6.3
Front thigh	18.8±6.4	19.9±6.3	19.3±6.4
Medial calf	14.3±4.8	14.4±4.9	14.3±4.8
Mid-axilla	6.7±2.9	7.0±4.4	6.8±3.6
Sum of 9 skinfolds	96.3±37.9	98.8±43.0	97.6±40.8
LIPOMETER			
Neck	2.8±2.8	3.2±2.8	3.0±2.8
Triceps	7.4±2.9	8.7±3.3*	8.0±3.1
Biceps	3.4±2.4	4.8±2.5*	4.0±2.5
Upper back	3.4±2.6	4.2±3.5	3.8±3.0
Front chest	5.6±4.4	6.1±4.9*	5.8±4.6
Lateral chest	2.9±2.9	3.6±4.7	3.2±3.8
Upper abdominal	5.5±4.9	6.3±6.1	5.9±5.5
Lower abdominal	6.7±4.6	7.0±5.1	6.8±4.8
Lower back	6.0±2.9	6.8±3.6	6.4±3.3
Hip	6.5±5.1	7.2±5.3	6.8±5.1
Front thigh	5.8±2.6	7.3±2.9*	6.5±2.8
Lateral thigh	6.0±2.7	7.2±2.3*	6.6±2.6
Rear thigh	4.6±2.1	4.6±2.0	4.6±2.1
Inner thigh	6.1±2.9	8.1±3.3*	7.0±3.2
Calf	3.1±1.4	3.6±1.8	3.6±1.6
Sum of 15 SAT-layers	74.6±39.4	88.2±45.2	82.2±42.3

*significantly different ($p<0.05–0.01$).

thicknesses or in the sum of nine skinfold thicknesses measured by skinfold caliper. However, the subcutaneous adipose tissue measured by LIPOMETER at some sites (*triceps, biceps, front chest, front thigh, lateral thigh, inner thigh*) was significantly ($p<0.05$) thicker in girls compared with boys. The sum of 15 SAT-layers was not different between boys and girls. The mean body impedance values are presented in Table 36. At all three frequencies, the impedance was significantly higher in girls compared with boys.

Table 36. Body impedance measured at different frequencies in children.

	Boys	**Girls**	**Total**
5 kHz	604.9±79.5	647.4±56.0*	624.2±72.7
50 kHz	562.3±63.7	599.4±50.5*	579.1±60.7
200 kHz	509.5±58.6	545.2±45.2*	525.7±55.6

*significantly different (p<0.05–0.01).

There were significant relationships between body mass and all nine measured skinfold thicknesses (boys: r=0.41–0.63; girls: r=0.58–0.78; total group: r=0.48–0.70). However, the SAT-layers measured by LIPOMETER were not significantly correlated with body mass in the total group. In boys, SAT-layers at *triceps*, *front thigh*, *lateral thigh*, *rear thigh* and *calf* sites did not correlate significantly with body mass. However, the relationship was significant at the other measured SAT-layers sites (r=0.28–0.50). In girls, SAT-layers at *front thigh*, *lateral thigh* and *calf* sites did not correlate significantly with body mass, while the relationship was significant for other measured layers sites (r=0.33–0.68). As a rule, body height was not significantly related to the subcutaneous adipose tissue thickness. In girls, most of the skinfold thicknesses measured by caliper correlated significantly with body height (r=0.31–0.43), except for skinfold thicknesses measured at *triceps*, *biceps*, and *medial calf* sites. BMI correlated significantly with all measured skinfold thicknesses in boys (r=0.58–0.79), girls (r=0.70–0.87) and the total group (r=0.63–0.80). Similarly, most of the SAT-layers measured by LIPOMETER correlated significantly in boys (r=0.30–0.66), except for the *front thigh* and *lateral thigh* SAT-layer. In girls, all SAT-layers measured by LIPOMETER were significantly related to BMI value (r=0.44–0.81), except for the *lateral thigh* SAT-layer. Pearson correlation coefficients between subcutaneous adipose tissue thicknesses measured by skinfold caliper or LIPOMETER correlated highly with each other except between *lateral thigh* and *supraspinale* sites in girls. The sum of nine skinfolds (caliper) correlated significantly with the sum of 15 SAT-layers (LIPOMETER) both in boys (r=0.83) and girls (r=0.89). Figure 3 presents the results of the Bland-Altman analysis for skinfold thickness and SAT-layers both in boys and girls in *biceps, triceps* and *front thigh*. Comparison of the two methods showed wide differences between the methods.

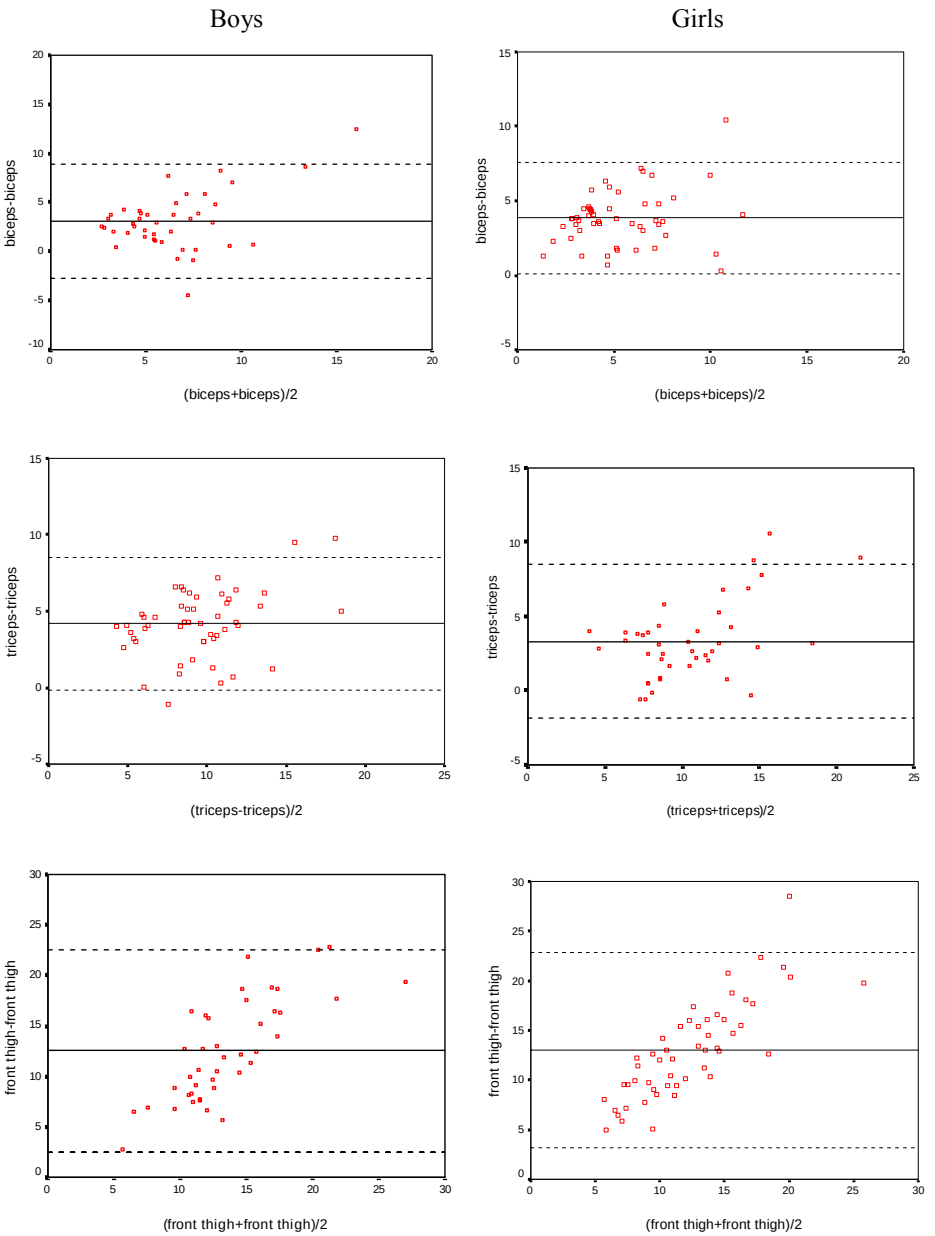

Figure 3. Bland-Altman plots of *biceps*, *triceps* and *front thigh* thicknesses between the skinfold caliper (in x axis) and LIPOMETER (in y axis) methods in boys and girls.

Bioelectrical impedance at 50 kHz significantly correlated with body mass (r=–0.47 in boys, r=–0.46 in girls, r=–0.47 in the total group) and BMI (r=–0.47

in boys and r=–0.48 in girls). The relationship between bioelectrical impedance at 50 kHz and body height was significant only for girls (r=–0.42). Pearson correlations between body impedance at three frequencies and adipose tissue thicknesses measured by skinfold caliper or LIPOMETER are presented in Table 37. Skinfold thicknesses measured by skinfold caliper did not correlate significantly with body impedance measured at all three frequencies. However, the SAT-layers measured by LIPOMETER at *triceps, front thigh, lateral thigh* and *rear thigh* in boys and at the *lateral thigh* in girls correlated with body impedance measured at 50 kHz. The sum of 9 skinfolds and 15 SAT-layers did no correlate significantly with body impedance in any of the groups.

Table 37. Pearson correlations between body impedance and adipose tissue thicknesses in children.

	Boys			Girls			Total		
	5 kHz	**50 kHz**	**200 kHz**	**5 kHz**	**50 kHz**	**200 kHz**	**5 kHz**	**50 kHz**	**200 kHz**
Skinfold Caliper									
Triceps	–0.02	0.17	0.17	–0.06	–0.11	–0.07	0.09	0.07	–0.08
Subscapular	–0.32**	–0.02	–0.02	–0.05	–0.11	–0.09	–0.03	–0.04	–0.17
Biceps	–0.20	0.09	0.09	–0.10	–0.17	–0.14	0.03	0.01	–0.10
Iliac crest	–0.26	–0.01	–0.01	–0.19	–0.26	–0.23	–0.11	0.01	–0.04
Supraspinale	–0.24	0.02	0.02	–0.21	–0.26	–0.24	–0.07	–0.09	–0.19
Abdominal	–0.23	0.07	0.08	–0.16	–0.25	–0.23	–0.06	–0.07	–0.22*
Front thigh	–0.07	0.19	0.12	–0.05	–0.11	–0.08	0.12	–0.12	–0.24*
Medial calf	–0.17	0.06	0.08	–0.11	–0.14	–0.11	0.01	–0.01	–0.14
Mid-axilla	–0.30*	–0.06	–0.06	–0.15	–0.20	–0.18	–0.08	–0.10	–0.19
Sum of 9 skinfolds	0.11	0.07	0.09	–0.16	–0.20	–0.18	0.08	–0.16	0.20
LIPOMETER									
Neck	–0.29*	0.17	0.17	–0.08	–0.13	–0.10	0.09	0.07	–0.18
Triceps	0.17	0.37**	0.39**	0.01	–0.04	0.01	0.28**	0.24*	0.16
Biceps	0.07	0.22	0.25	–0.19	–0.14	–0.09	0.19	0.16	0.06
Upper back	–0.17	0.14	0.15	–0.03	–0.09	–0.06	0.09	0.07	–0.05
Front chest	–0.11	0.17	0.19	0.05	0.02	0.05	0.14	0.12	–0.03
Lateral chest	–0.20	0.02	0.03	–0.14	–0.18	–0.14	–0.02	–0.05	0.12
Upper abdominal	–0.18	0.05	0.06	–0.03	–0.10	–0.07	0.03	0.01	–0.08
Lower abdominal	–0.02	0.13	0.14	–0.14	–0.20	–0.16	0.03	0.01	–0.05
Lower back	0.05	0.21	0.23	–0.13	–0.19	–0.16	0.09	0.07	0.01
Hip	–0.10	0.07	0.08	–0.14	–0.19	–0.17	0.01	–0.01	–0.08
Front thigh	0.29*	0.37**	0.39**	0.26	0.23	0.24	0.38	0.36**	0.32**
Lateral thigh	0.30*	0.45**	0.46**	0.38*	0.34*	0.35*	0.46**	0.45**	0.34**
Rear thigh	0.29*	0.37**	0.37**	0.22	0.19	0.22	0.30*	0.34**	0.40**
Inner thigh	0.14	0.23	0.25	0.09	0.04	0.06	0.11	0.12	0.17
Calf	0.11	0.15	0.16	–0.01	–0.06	–0.04	0.08	0.10	0.10
Sum of 15 SAT-layers	0.09	0.25	0.19	0.08	–0.06	0.20	0.04	0.16	0.11

*p<0.05;
**p<0.01.

Stepwise multiple regression analysis indicated that only the *iliac crest* and *front thigh* from the skinfold thicknesses measured by caliper had significant effect on body impedance at 50 kHz in the total group (Table 38). These skinfold thicknesses characterized only 5.7–12.0% of the total variance (R^2 ×100). From the 15 SAT-layers, only two sites were selected for the regression models. The most important site was the *lateral thigh* layer which characterized 20.0%, 11.9%, and 13.6% of the total variance in boys, girls, and the total group, respectively. In the second model, the different layers were added (*hip* in boys, *lower abdomen* in girls and *neck* in the total group) for all three groups.

Table 38. Stepwise multiple regression analysis for impedance at 50 kHz dependent on subcutaneous adipose tissue thicknesses measured by skinfold caliper and LIPO-METER.

Step and variable	Group	Regression equation for impedance at 50 kHz (Ω)	R	R^2 ×100	SEE
Skinfold caliper					
1. Iliac crest	Total	–2.86 iliac crest + 655.1	0.24	5.7	71.7
2. Front thigh		–6.78 iliac crest + 4.75 front thigh + 605.95	0.35	12.0	69.6
LIPOMETER					
1. Lateral thigh	Boys	10.54 lateral thigh + 498.82	0.45	20.0	57.5
2. Hip		15.05 lateral thigh – 3.98 hip + 497.32	0.51	26.3	55.7
1. Lateral thigh	Girls	7.40 lateral thigh + 546.25	0.35	11.9	47.9
2. Lower abdominal		11.45 lateral thigh – 4.22 lower abdominal + 546.77	0.52	26.9	44.2
1. Lateral thigh	Total	10.30 lateral thigh + 556.73	0.37	13.6	67.9
2. Neck		15.84 lateral thigh — 11.23 neck + 554.43	0.54	28.8	62.0

6. DISCUSSION

6.1. Longitudinal changes of anthropometrical parameters and bioelectrical impedance during puberty (Study I)

The tracking coefficient during four years is mostly high. However, the results of the present study did not confirm our hypothesis that the somatotype components are better predictors of anthropometry than other often used anthropometrical parameters. During puberty the body impedance decreased and impedance index increased and the tracking was high.

According to Tanner *et al.* (1975), the onset of puberty corresponds to a skeletal age of approximately 11 years in girls and 12 years in boys. The peak height velocity in girls is at age 12 with an average height increase of 9 cm/year (Marshall and Tanner, 1969) and in boys approximately 2 years later with height increase of about 10.3 cm/year (Marshall and Tanner, 1970). In our study, data about the individual peak height velocities are not available. However, the mean body height increase in boys was highest between 12 and 13 years of age (third and fourth measurement, mean increase 6.9 cm per year) and in girls between 11 and 12 years of age (second and third measurement, mean increase 6.3 cm per year). One of the weaknesses of the present study is probably the fact that we did not measure the children for at least one more year, at least in boys. Previous investigations confirm that in boys, the peak body mass velocity is about at the age of 14 and averages 9 kg/year (Tanner *et al.,* 1975). In girls, the peak body mass gain lies behind peak height velocity by approximately 6 months and reaches 8.3 kg/year at about 12.5 years of age (Tanner *et al.,* 1975). In our study, the peak increase in body mass in boys and girls was between 11 and 12 years of age — 5.7 and 5.2 kg, respectively (see Table 9). At that time the tracking correlations were also very high (r=0.954 in boys and r=0.966 in girls).

A previous study by Rolland-Cachera *et al.* (1990) has indicated that the relationship between adult and childhood skinfold ratio measurements is weak in boys and slightly stronger in girls. In our study, the development of skinfold thicknesses is different in trunk and extremities regions and there are sex-specific differences during puberty. As in Tanner and Whitehouse's (1975a) cross-sectional study, in our investigation with increasing the age, the skinfold thicknesses on the extremities decreased and trunk thickness continued to increase. However, in girls, both arm and trunk skinfold thicknesses increased (see Table 13). The decline in skinfold thicknesses in boys probably reflects the regional growth of the FFM.

Carter *et al.* (1997) emphasized that in studies of children and adolescent growth, the measurement of somatotype is particularly important because it recognizes that individual somatotype components change over time. In our study, during puberty, endomorphy increased especially rapidly in boys at the

beginning of puberty (see Table 9). However, compared with other somatotype components, the tracking coefficients were relatively low (see Table 18). This increase is accompanied by the increase of most of the skinfold thicknesses. This is in agreement with other studies (Carter and Heath, 1990). Mesomorphy was stable during puberty in boys and decreased in girls (see Table 9). With increasing the time interval, the tracking coefficients decreased rapidly (see Table 18). We agree with the results of several cross-sectional studies that the changes in somatotype components are sometimes contradictory (Tanner and Whitehouse, 1975b) and also depend on sex (Duquet *et al.*,1993; Eiben and Nemeth, 2001).

Several BIA equations are presented for calculating different body composition parameters in children (Hills *et al.,* 2001; Boileau, 1996; Houtkooper *et al.,* 1992). However, all the regression equations are very group-specific and developed cross-sectionally against reference measures. Secondly, body composition is subject to very rapid changes during puberty, and this may explain why there is no longer a clear difference between the methods in that period. This suggests that it is probably better to use only body impedance and calculated impedance index. However, the disadvantages of BIA measurements include: 1) the insensitivity of the method for detecting small changes in body composition in individuals followed over time; 2) dependency of the estimates on the relative amounts of extra- and intracellular water; and 3) the potential distortion of values due to body configuration, as in abdominal obesity (Hills *et al.,* 2001; Deurenberg, 1994). In our study, as a rule, body impedance decreased every year. It is interesting because it is well known that the hydration level of the fat-free body is higher in prepubertal children than at later ages and especially in boys, fat tissue decreased at the end of puberty. In contrast, the calculated impedance index increased with age, which is in accordance with other investigations (Davies *et al.,* 1988).

In conclusion, our results indicate that during puberty, the detailed anthropometrical parameters and body impedance tracked highly. However, the tracking of PAI is significant but relatively low.

6.2. Longitudinal reproducibility of anthropometrical parameters during puberty (Study II)

The reproducibility of body height and body mass in our study was high. Wilmore *et al.* (1997) reported the ICCs for body height and body mass ranging from r=0.97 to r=1.00 in adults, which is very similar with our results (see Table 24). Slightly higher ICCs and lower TEs then our results have been presented for body height and body mass by Bouchard (1985) in children and adults.

Skinfold thickness is accepted as a body fatness predictor for the following reasons: 1) about 40–60% of total body fat is in the subcutaneous region of the body; and 2) skinfold thickness can be directly measured using a well-calibrated caliper (Wang *et al.,* 2000). Standardized methodology, including positioning of the instrument and the subject, a well-trained data collector and practising until results are consistent can increase the reproducibility. Special attention to locating the site, grasping the skin, and assuring that the caliper is at a 90^{o} angle relative to the grasped skinfold are essentials for high reproducibility (Wang *et al.,* 2000). In our study (see Table 20), the reproducibility (ICC for the skinfolds) was high — as a rule higher than r=0.95, which is slightly higher than presented by Mueller and Malina (1987) in children of 12 to 17 years of age or Hass and Flegal (1981) in adults. The TEs in our investigation were quite small and similar to other studies (Bouchard, 1985). It is surprising that the ICCs were highest and TEs and CVs lowest during the second year of measurement when the children were about 10–11 years old. On the other hand, the ICCs were slightly higher in girls compared with boys (r=0.992 and r=0.986, respectively) and the mean TEs in girls were lower than in boys (0.36 and 0.56 mm, respectively). It is very difficult to explain the best reproducibility results before the beginning of puberty, i.e., second year of measurement and especially in girls. However, it is a wellknown fact that skinfolds do not increase progressively with age during growth. They show gains and losses at times when body FM may be increasing progressively (Norgan, 1991). On the other hand, Zerfas (1985) accepted higher measurement differences in children compared with adults.

In our study, the question has arisen whether fat patterns can be identified by body girths rather than skinfold thicknesses or like measures of subcutaneous fat (Ashwell *et al.,* 1982). The advantages of girths are: 1) they are more reliable than skinfold thicknesses; and 2) they can always be measured, whereas a recognizable fold of skin and subcutaneous fat cannot be obtained in many obese subjects (Bray *et al.,* 2001). The ICCs were slightly lower and TEs higher in the girth than skinfolds measurements (see Tables 26 and 27 respectively). Similarly to skinfolds, the mean ICCs and TEs in girth measurements were the best during the second year of measurement series. As a rule, CVs were less than <2.0%, which was the mean criterion for circumferences measured at eight sites in the study of Wang *et al.* (2000). Ulijaszek and Kerr (1999) concluded that the lower levels of ICCs have been achieved for waist and hip circumferences. In our study, ICCs were relatively low in chest, waist and gluteal (hip), ankle and thigh in boys (see Table 26) and neck, arm, forearm, ankle and thigh in girls (see Table 27).

Compared with skinfold thickness and girth measurements, there are less data available about the reproducibility of length parameters. In our study, the reproducibility of length parameters was about the same as for girth parameters. The lowest TE and highest ICC occurred during the second year of measurement. In both boys and girls, ICCs were lowest on the tibiale laterale to

floor and tibiale mediale-sphy.tibiale sites (see Table 28). This is partly understandable as the measurement errors are usually greater in the younger age groups and among smallest children within any age group (Ulijaszek, 1997).

In conclusion, the reproducibility of girths, lengths and breadths/lengths in children was very high and the reproducibility of skinfolds was high. Furthermore, the reproducibility was very high immediately before puberty (i.e., in the second year of measurements).

6.3. Relationships between different anthropometrical parameters, bioelectrical impedance and body composition (Study III)

The popularity of BIA as a method for assessing body composition is due, in large part, to its simplicity. However, several limiting factors may influence the accuracy of the BIA measurement (Kushner *et al.,* 1996). Less information is available about the influence of different anthropometrical parameters to the body impedance. For example, Houtkooper *et al.* (1987) have indicated that more information is needed regarding the size and shape of the conductor than that provided by height.

In our study, the measured skinfold thicknesses did not significantly influence body impedance or impedance index in children (see Table 32). To our knowledge, analyses of the associations of skinfold thicknesses with body impedance have not yet been published about children. However, small, but significant negative relationships have been reported between body impedance and some skinfold thicknesses (*subscapular* and *midaxillary* in men and *subscapular*, *midaxillary*, *paraumbilical* and *biceps* in women) in young men and women (Baumgartner *et al.* 1987). Surprisingly, in that study, the mean of the seven skinfold thicknesses was not significantly related to the body impedance in either sex (Baumgartner *et al.,* 1987).

Wrist girth was the most important parameter influencing the body impedance or impedance index in boys (58% or 75%; R^2x100), while calf and gluteal girths characterized 50% (R^2x100) of the total variance in girls. Wrist and calf girths characterized 77% (R^2x100) of the impedance index in boys (see Table 32). These results are somewhat contradictory between sexes. In adults, upper arm and calf girths had significant negative correlations with body impedance (Baumgartner *et al.,* 1987). The girth parameters are important as the human body is theoretically divided by cylinders: nine cylinders (Diffrient *et al.,* 1974), or five cylinders (Organ *et al.,* 1994) in several segmental bioelectrical impedance analysis. Girths do indeed seem to be more repeatable than skinfold thicknesses (Mueller and Malina, 1987). However, Jackson and Pollock (1976) suggest that girths may be less useful as they represent both fatness and leanness.

Theoretically, BIA method is based on Ohm's Law which relates the body impedance of a cylindrical conductor to its volume, and length to the power of two (Hoffer *et al.,* 1979; Jenin *et al.,* 1975). In prediction equations for BIA, frequently, the length of the biological conductor is taken to be body height. Surprisingly, as in some other studies (Grieve and Henneberg, 1998), the length parameters did not correlate significantly with body impedance in our study (see Table 32). However, the length parameters of legs influenced impedance index both in boys and girls by 50% and 81% (R^2x100), respectively. This could possibly be explained by the fact that impedance index consists of the main length parameter (i.e., body height). However, in contrast, it has been confirmed that BIA overestimates %FM in young adults with relatively long limbs (Snijder *et al.,* 1999). In contrast, Eisenkölbl *et al.* (2001) indicated that the underestimation of %FM measured by BIA compared to DXA method in obese children is three times higher with boys than with girls.

Some of the used breadth/length parameters influenced significantly body impedance and impedance index (see Table 32). In girls, some trunk parameters influenced first at all body impedance or impedance index (see Table 32). In boys, the femur breadth was the main predictor of body impedance.

Our results indicate that in spite of the theoretical backround that the human body's electrical impedance is a function of the distribution of water and electrolytes. Accordingly, Deurenberg *et al.* (1990) concluded that in boys aged 10–15 year and girls aged 10–12 years, the relationship between body composition and body impedance was altered because of age-related differences in electrolyte concentration in the extracellular space relative to the intracellular space and secondly age-related differences in tissue composition with regard to electrolyte concentration. However, Kushner *et al.* (1992) showed, and Goran *et al.* (1993) cross-validated that the relationship between impedance index and total body water is robust across a wide age range. Among the various compartments in the body, anthropometrical parameters and especially girth significantly influenced the body impedance in children.

In conclusion, the results of the present study indicate that the variation in anthropometry highly influenced the variance observed in body impedance in children, and the girth values were better predictors of body impedance.

6.4. Influence of anthropometrical parameters and bioelectrical impedance analysis on body fat measured by dual-energy X-ray absorptiometry (Studies III, IV)

Dual-energy X-ray absorptiometry is frequently used as a criterion method on body composition analysis even in children (Reilly, 1998). DXA has the advantage of being a 3C model that quantifies fat, soft lean tissue and bone mineral, and also yields regional as well as total body volume. However, under-

hydration or over-hydration cannot be measured with DXA. Stepwise multiple regression analysis indicated that there were significant relationships between FM measured on total body or separately on trunk, arms and legs and skinfold thicknesses measured on specific sites in spite of the fact that skinfold thicknesses measured by caliper using double-fold and compressed thicknesses. Total body FM comparison with nine measured skinfold thicknesses indicates a large difference between sexes. *Supraspinale* and *iliac crest* skinfold thicknesses characterized 92% (R^2x100) of the total variance in boys and the most important is the abdominal skinfold thickness (59%) in girls. Bray *et al.* (2001) concluded that *biceps* skinfold thickness had the highest predictive value of any single skinfold thickness compared with FM measured by DXA. In separate body parts, skinfold thicknesses characterized the specific FM better in boys than in girls (see Tables 33 and 34). In Portuguese children of about the same age as children in this study, Teixeira *et al.* (2001) indicated that the sum of three trunk skinfolds was highly ($p<0.001$) related to total trunk fat mass measured by DXA. In comparison, Peters *et al.* (1994), by using magnetic resonance imaging, indicated that the horizontal abdominal skinfold had the strongest correlation with total body fat in girls.

From the somatotype components only mesomorphy, which mirrors the developmental stage of the musculo–skeletal systems characterized 35% of the body impedance in boys (see Table 32).These results are similar with our previous study (Jürimäe *et al.,* 2000). In contrast, endomorphy, which is a measure of body fat content, highly characterized total body FM measured by DXA in boys (88%) and in girls (52%; see Table 33). Similarly, Slaughter and Lohman (1976) already described the significant relationship of endomorphy with total fat content as assessed by the ^{40}K-labelling technique. Ectomorphy, which is a reflection of the body linearity, did not influence the body impedance or body FM. This confirms again that the length of the body is not a significant parameter to the body impedance or fat tissue mass. The results of this study indicate that the selected skinfold thicknesses highly predicted the total body, trunk, arms and legs fat mass measured by DXA.

In our study, the subcutaneous adipose tissue thicknesses were measured by using two different methods — traditional skinfold thickness measurement using skinfold calipers, and the new LIPOMETER. However, the anatomical points of the measurement were different according to the ISAK (Norton and Olds, 1996) and LIPOMETER (Möller *et al.,* 1994) standard recommendations. Surprisingly, the relationship between subcutaneous adipose tissue thicknesses measured by these two methods at the same anatomical points was not higher than that between other measured points. Only correlations at the triceps (*r=0.80, r=0.82, r=0.80* in boys, girls and the total group), subscapular region [upper back (*r=0.87, r=0.89, r=0.88*)] and abdomen [lower abdomen (*r=0.82, r=0.86, r=0.88*)] (see Table 37) were slightly higher than the correlations between other measured anatomical points. The relationships between data from boys and girls are very similar and are in good agreement with Malina and

Bouchard (1988), who indicate that the relative distribution of trunk and extremity subcutaneous fat during childhood is rather stable and that the ratio of trunk to extremity skinfold thickness is similar in boys and girls. Furthermore, triceps and subscapular skinfolds are frequently recommended for the measurement of body composition in children (Boileau *et al.,* 1981; Nelson and Nelson, 1986).

Theoretically, all SAT-layers measured by LIPOMETER (single non-compressed thickness) should be approximately two times thinner than skinfold thicknesses measured by caliper (double compressed thickness). However, in this study, differences were rather high depending on the measurement site (see Table 35, Fig. 3). These differences probably depend on the mistakes made when palpating specific anatomical points as well as other known mistakes related to caliper use. One hypothesis tested in this study was that there are different relationships between body impedance and subcutaneous adipose tissue depending on the measurement method used. This hypothesis was only partially upheld. The main anthropometric parameter influencing body impedance was the thigh in both boys and girls using caliper and LIPOMETER methods. However, subcutaneous adipose tissue on the thigh region characterized 20% of the total variance in body impedance at most. Our results are partially in agreement with previous studies indicating that the main factors influencing body impedance are the arm and leg (Katch *et al.,* 1974). The human body as a conductor is highly anisotropic, especially in the trunk region, which additionally indicates that the relationship between whole-body impedance and the conductor volume is not strictly linear (Brodie *et al.,* 1998). Our results confirm the fact that the thinner segments of the body (i.e. legs) provide the greatest impedance, particularly in tall people (Fuller and Elia, 1989). Finally, the differential compression of adipose tissue and the gender differences of skin thickness are well known (Martin *et al.,* 1992).

In conclusion, the influence of subcutaneous adipose tissue on body impedance is relatively low. However, the single SAT-layers have slightly more influence on body impedance than skinfold thicknesses measured by skinfold caliper. Finally, the sum of skinfolds or SAT-layers did not correlate significantly with body impedance in boys, girls or the total group.

7. CONCLUSIONS

1. Measured anthropometrical parameters (skinfolds, girths, lengths, breadths/ lengths) and body impedance over different levels of sexual maturation tracked highly during puberty in boys and girls.
2. Reproducibility of girths, lengths and breadths/lengths during puberty (measured four times with an interval of one year) is high. The reproducibility of skinfolds was slightly lower. The reproducibility appears to be highest immediately before puberty in boys and girls.
3. The variation in anthropometry highly influenced the variance observed in bioelectrical impedance in children, and the girth values were better predictors of bioelectrical impedance. Selected skinfold thicknesses highly predicted the total body, trunk, arms and legs fat mass measured by means of dual-energy X-ray absorptiometry in boys and girls.
4. The influence of subcutaneous adipose tissue on body impedance is relatively low in children. Subcutaneous adipose tissue layers, measured by LIPOMETER, have slightly higher influence on body impedance than skinfold thicknesses measured by skinfold caliper. The sum of skinfolds measured by skinfold caliper or LIPOMETER is not related to body impedance in boys and girls.

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SUMMARY IN ESTONIAN

Antropomeetriliste näitajate, keha koostise ning keha bioelektrilise takistuse muutused puberteediperioodi vältel: longitudinaaluuring

Sissejuhatus

Täiskasvanute tervis on otseselt seotud nende tervisega lapseeas. Noorukiiga, eriti puberteediiga, on tundlik ning üks elu kriitilisemaid arenguperioode, mida iseloomustavad kiired keha suuruse, kuju ja koostise muutused. On tehtud suur hulk uuringuid, milles on uuritud laste antropomeetrilisi ja/või keha koostise parameetreid, kasutades mitmesuguseid mõõtmismeetodeid. Samas ei ole nii põhjalikult dokumenteeritud spetsiifilisi andmeid kasvu, antropomeetriliste näitajate (nt nahavoldid, ümbermõõdud, pikkused ja diameetrid) kohta. Meie teadmiste kohaselt ei ole tehtud ühtegi uurimistööd, mis kasutaks kõiki neid parameetreid, et longitudinaalselt uurida Eesti poiste ja tüdrukute kasvumustrit puberteediea vältel.

Uurimustöö ülesanded:

Uurimustöö peamine eesmärk oli uurida longitudinaalselt antropomeetriliste näitajate ja keha koostise parameetrite muutusi puberteediperioodi vältel ning esitada mõned uued aspektid, mis mõjutavad antropomeetriliste parameetrite mõõtmiste kvaliteeti ja keha koostist Eesti poistel ja tüdrukutel puberteediperioodi jooksul.

Vastavalt uurimustöö eesmärgile püstitati järgnevad ülesanded:

1. Iseloomustada puberteediperioodi jooksul toimuvaid antropomeetriliste näitajate (nahavoltide paksused, ümbermõõdud, pikkused ja diameetrid) muutusi sõltuvalt sugulise küpsemise astmest nelja aasta vältel.
2. Uurida antropomeetriliste näitajate ja keha koostise parameetrite korratavust longitudinaalselt puberteediperioodi vältel neljal korral.
3. Uurida antropomeetriliste näitajate ja somatotüübi komponentide mõju keha koostisele, määratuna BIA- ja DXA-meetodil puberteedialistel lastel.
4. Leida seoseid keha rasvkoe hulga vahel, määratuna DXA-meetodil, ning nahaaluse rasvkoe paksuse vahel, määratuna kas kaliibri või LIPOMEETRIGA, puberteedialistel lastel.

Uuritavad ja metoodika

Uuringus osalesid 81 poissi ja 86 tüdrukut vanuses 9–11 aastat. Lastel määrati sugulise küpsuse aste Tanneri skaala järgi (Tanner, 1962). Laste kehalise aktiivsuse kindlakstegemiseks kasutati "Kehalise aktiivsuse ankeeti" (Telama jt, 1996). Lapsi mõõdeti nelja aasta jooksul kord aastas (jaanuarist veebruarini). Mõõdeti laste keha pikkus ja keha mass. Kalkuleeriti kehamassiindeks — KMI. Antropomeetrilisteks mõõtmisteks kasutati Rahvusvahelise Kinantropomeetria

Ühingu soovitatud skeemi. Lisaks arvutati 9 nahavoldi paksuste summa. Kõiki antropomeetrilisi mõõtmisi tehti kolm korda, kusjuures töös võeti arvesse kolme keskmine. Somatotüüp määrati Heathi ja Carteri järgi (Heath ja Carter, 1990), leides ekto-, endo- ja mesomorfsed komponendid. Keha koostist määrati multisagedusliku bioelektrilise takistuse määramise meetodil, kasutades aparaati MULTISCAN 5000 (BODYSTAT Ltd, Suurbritannia). Käesolevas töös kasutati järgmisi sagedusi: 5 kHz, mis iseloomustab keha ekstratsellulaarse vedeliku hulka, 50 kHz, mis iseloomustab keha üldist vedelike hulka ja 200 kHz, mis iseloomustab keha intratsellulaarset vedelike hulka. Arvutati keha takistusindeks (keha pikkus (m^2)/ keha takistus (Ω), mis on mõõdetud sagedusel 50 kHz). Antropomeetriliste näitajate määramist korrati: 21 poisil ja 18 tüdrukul tehti antropomeetrilised mõõtmised identsetes tingimustes kaks korda ühenädalase intervalliga nelja aasta jooksul. Teist korda mõõdeti ka keha koostist bioelektrilise takistuse määramise meetodil. 52 poisil ja 44 tüdrukul mõõdeti nahaaluse rasvkoe paksust optilise seadmega LIPOMEETER 15 keha punktist (Möller jt, 1994). Arvutati 15 nahaaluse rasvkoekihi summa. Keha koostis määrati DXA-ga, kasutades DPX-IQ densitiomeetrit (Lunar Corp, Madison, WI, USA) 26 poisil ja 27 tüdrukul. Kalkuleeriti kogu keha rasva mass ja eraldi käte, jalgade ning kere rasvamass.

Järeldused

1. Antropomeetriliste parameetrite ja keha takistuse muutuste uurimisel puberteediperioodil tuleb arvestada nii sugulise küpsuse astmetega kui ka kronoloogilise vanusega.
2. Ümbermõõtude, pikkuste ja diameetrite mõõtmise korratavus puberteediea jooksul (mõõdeti neli korda üheaastase intervalliga) oli väga kõrge ja nahavoltide puhul kõrge. Korratavus näib olevat kõrgeim vahetult enne puberteediperioodi algust nii poistel kui tüdrukutel.
3. Erinevused laste antropomeetrilistes näitajates mõjutasid oluliselt keha bioelektrilist takistust. Kõige rohkem olid bioelektrilise takistusega seotud ümbermõõdud. Nahavoltide paksused olid seotud usutavalt keha rasvasisaldusega, mõõdetuna DXA-ga keha erinevates piirkondades.
4. Nahaaluse rasvkoe mõju keha takistusele on laste puhul suhteliselt väike. Nahaaluse rasvkoe kihid, määratuna LIPOMEETRIGA, mõjutavad keha takistust rohkem kui nahavoltide paksused, mis on määratud kaliibriga. Nahavoltide paksuste summa, mõõdetuna nahavoldi kaliibriga või LIPOMEETRIGA, ei ole seotud keha takistusega.

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Peamised uurimisvaldkonnad

Laste antropomeetria, keha koostis, kehaline aktiivsus