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Gender Differences in Body Composition from Childhood to Old Age: An Evolutionary Point of View

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ABSTRACT In this cross-sectional study gender differences in body composition (relative fat mass and lean body mass adjusted by height) were analyzed among 869 girls and 780 boys aging between 6 and 18 years and 513 adult women and 412 adult men aging between 19 and 92 years. Body composition was determined by BIA method among children and adolescents and dual energy x-ray absorptiometry (DEXA) among adults. It could be shown that males and females differed significantly in body composition throughout life. Even during prepuberty, girls exhibited a significantly higher amount of body fat and a significantly lower amount of lean body mass than their male counterparts. These gender differences are found throughout life. The observed results are interpreted in a proximate and an ultimate sense. Furthermore the impact of modern life style in industrialized countries is discussed.

INTRODUCTION

Sexual size dimorphism is a common phenomenon among various animal species. While in many species females are substantially larger than their male counterparts, in mammals commonly the opposite is true (Rode et al. 2006; Bulte and Bloin-Demers 2009). Beside size dimorphism, some animal species also show significant average sex differences in body composition. Significant sex differences in the amount of body fat and lean body mass are documented for waterfowls such as mallards (Boos et al. 2002), various snakes such as Vipera aspis (Bonnet et al. 1998) and small mammals such as wood rats (Schulte-Hostedde et al. 2001). Sexual dimorphism in size as well as in body composition is best studied among humans. As in many other primate species human males exceed human females in size. Adult human males are on average 7% taller than females. Although gender differences in body size are observable even during the first trimester of pregnancy (Bukowski et al. 2007), these differences emerge primarily during adolescence because during childhood size dimorphism remains minor until the onset of puberty (Wells 2007; Loomba-Albrecht and Styne 2009). Regarding body composition gender differences are found among newborns. Newborn girls exhibited a significantly higher amount in relative fat mass and a lower amount in lean body mass in comparison to newborn boys (Fields et al. 2009). Nevertheless these differences diminish by 6 months of age, no sexual dimorphisms in body composition is found anymore (Fields et al. 2009). For a long time any sexual dimorphism in body composition up to the onset of puberty was denied (Forest 1981; Forbes 1987), however during the last 20 years there is increasing evidence that sex differences in body composition are observable before puberty (Faulkner et al. 1993; Nelson et al. 1997; Taylor et al. 1997; Mast et al. 1998; Kirchengast 2002; Wells 2007). During puberty and adolescence sexual dimorphism in body composition increases (Loomba-Albrecht and Styne 2009) and during adulthood a considerable dimorphism in body composition between males and females is established (Wells 2007). This typical human sexual dimorphism in body composition is characterized by a substantially higher amount of body fat and a substantially lower amount of lean body mass among women. These patterns of sexual dimorphism are physiologically caused by hormonal factors and hold across all human populations. Sexual dimorphism in body size or gender differences in body composition however has important implications on the study of human evolution and the development of differences in gender roles among societies too. Therefore a physiological approach to analyze gender differences in body composition is not enough. The aim of the present paper is to analyze gender differences in body composition from childhood to old age and to discuss these differences from an evolutionary point of view.

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SUBJECTS AND METHODS

Study Design and Procedure

In this cross-sectional study body composition data of children and adolescents were collected in various school of eastern Austria. In particular, schools in Vienna, Lower Austria and Burgenland were enrolled in the investigation. Austrian Medical school authority gave their consent to the data collection. Furthermore only children and adolescents whose parents gave their written consent were included in the sample. The adult subjects were recruited by newspaper advertising, broadcasting or via snowball system and originated from Vienna or neighboring Lower Austria. The examination took place at the Menox-out-patient-department for the treatment of climacteric symptoms in Vienna. The examination started an extensive anamnesis and documentation of individual case history, reproductive history, previous diseases, surgery, actual and past medication. All subjects with acute diseases or a history of chronic or metabolic bone disease, physical disabilities and a treatment with drugs that may influence body composition such as cortisone treatment were excluded from further analyses. Beside the objectives of the study, the right to withdraw at any time was explained. Strict confidentiality was ensured. The study was conducted in compliance with "Ethical principles for medical research involving human subjects" of Helsinki Declaration.

Subjects

869 girls and 780 boys aging between 6 and 18 years (x=12.6±3.1) were enrolled in the present study. The adult sample consisted of 513 women and 412 men aging between 19 and 92 years (x=51.7±15.2).

Anthropometrics and Weight Status

Stature was measured with a Martin anthropometer to the nearest millimetre according to the methods described by Knussmann (1988). Weight was recorded with a scale precise to *7-100g. The subjects wore only underwear. Body mass index (BMI) kg/m^2 was calculated in order to obtain information regarding the weight status. For children and adolescents the weight status was determined using the percentiles of the body mass index published by Kromeyer-Hausschild et al. (2001). According to the recommendations of Kromeyer-Hausschild et al. (2001) and the European Childhood obesity group (Zwiauer and Wabitsch 1997), the 90 percentile was taken as cut-off for overweight and the 97 percentile as cut-off for obesity for each sex separately. For adult subjects weight status was classified using the Body mass index categories published by the WHO (1995):

BMI < 16.00 = severe thinness
BMI 16.00-16.99 = moderate thinness
BMI 17.00-18.49 = mild thinness
BMI 18.50 – 24.99 = normal range (normal weight)
BMI 25.00-29.99 = overweight
BMI 30.00-39.99 = obese Grade I
BMI >40.00 = obese Grade II

Since only few individuals exhibited a BMI below 16.00, all individuals with a BMI lower than 18.50 were comprised to one group, classified as underweight. Furthermore, only extremely few individuals exhibited a BMI above 40.00, therefore all individuals with a BMI higher than 30.00 were classified as obese.

Body Composition Analyses

Body composition in children and adolescents was determined using a TBF 305 Body composition analyzer according to BIA-method. In this BIA-system two foot-pad electrodes are incorporated into a precision electronic scale. Impedance of the lower extremities and body weight are measured simultaneously while the subject is standing on the scale. The electrodes are in contact with the heels and soles of both feet. The impedance was measured with 4 terminals and uses a standard 50kHz-0.8mA sine wave constant current. The computer software in the machine then used the measured resistance, the programmed subjects gender, group (child, adult, athlete) and stature height and the measured weight to calculate the body density based on previously derived equations obtained from regression analyses with under water weighing. This was then applied automatically to the standard densiometric formula according to Brozek to calculate the fat percentage. In detail the following variables were determined: Total fat percentage (fat%), absolute fat mass (in kg) (FM), fat free body mss (in kg) FFBM and the total body water (in kg) TBW. The coefficient of variation for within days impedance measurements was 0.9% and the between days coefficient of variation was 2.1.%. The BIA-method using bipolar foot electrodes is described as useful and reliable technique for measuring body composition by several studies (Nunez et al. 1997; Tsui et al. 1998). According to Rowlands and Eston (2001), the leg to leg pressure contact electrode BIA systems has overall performance characteristics for impedance measurement and body composition analysis similar to convential arm-to-leg electrode BIA and offers the advantage of speed and ease measurement. Therefore, this method was especially useful in the present study because the Body fat analyzer was easy to transport to the school were data collection took place and the children were not worry, they had only to step on the scale and the determination of weight and body composition were performed simultaneously.

Body composition analyses among adult subjects were performed by dual-energy-x-ray absorptiometry (DEXA) using a Hologic 4000 scanner. DEXA measures total bone mineral content (BMC) and bone density (BD), fat mass and lean soft tissue mass with a precision (coefficient of variation) of 0.9, 4.7 and 1.5% respectively. The precision of abdominal fat mass and fat % is 4.3 % and 3.4% respectively (Svendsen et al. 1995). All scans were obtained by the same person. The extinction of x-rays dependent on the tissue measured and absolute and relative fat mass and lean body mass are estimated. The scanner uses an x-ray source, an internal wheel to calibrate BMC and an external luciate and aluminium phantom to determine the percentage of fat of each soft tissue sample scanned. The percentage of body fat is determined from the ratio of attenuation of the lower energy (70kVp) to that of higher energy (140 kVp) of the beam. This is calculated for all non-skeleton pixels. The scan time takes approximately 6 minutes and the radiation doses are relatively low with 0.1 mSievert. Default software readings provide lines positioned to divide separate body compartments such as head, upper and lower limbs and trunk.

Statistical Analyses

Statistical analyses were carried out by using SPSS program version 16.0 (Microsoft Corp.). After calculating descriptive statistics such as means, standard deviations, ranges of the body composition variables, student t-test and chi-squares (χ^2) were performed to test group differences with respect to their statistical significance. Linear regression analyses were computed in order to test the impact of sex and age on body composition.

RESULTS

Gender Differences in Weight Status

The percentages of underweight, normal weight, overweight and obesity according to sex and age are listed in table 1. Although statistically significant gender differences in weight status were only found for 14 and 15 year adolescents, some trends are observable. Underweight was always found more frequently among females. This was especially true of pubertal and adolescent girls aging between 11 and 16 years. During adulthood underweight was exclusively found among females, the prevalence of underweight however was also extremely low among females and did not exceed 3.9%. Regarding overweight and obesity the prevalence among children and adolescents not marked differences between girls and boys could be observed, although during puberty and early adolescence more boys than girls were classified as overweight or obese. During adulthood up to the 7th decade of life the prevalence of overweight and obesity increased and decreased after the age of 70 years (see Table 1).

Gender Differences in Body Composition

Childhood and Adolescence

Girls and boys of all age groups differed significantly in relative fat mass and relative lean mass ($p< 0.001$). As to be seen in Figures 1 and 2 girls exhibited always a significantly higher amount of body fat and a significantly lower amount of lean body mass adjusted for height. The mean gender differences in relative fat mass as well as in relative lean body mass remain more or less stabile up to puberty and increased significantly ($p<0.01$) during puberty and adolescence (see Figs. 3 and 4). The increasing mean gender differences in relative fat mass are mainly due to the marked decrease in relative fat

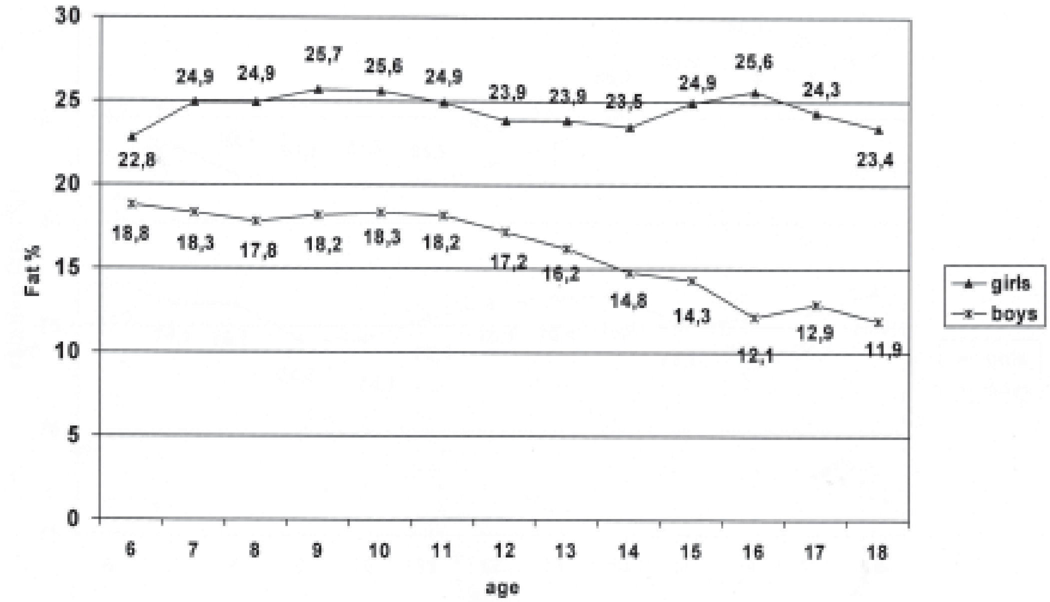

Fig. 1. Relative fat mass (%) according to sex during childhood and adolescense

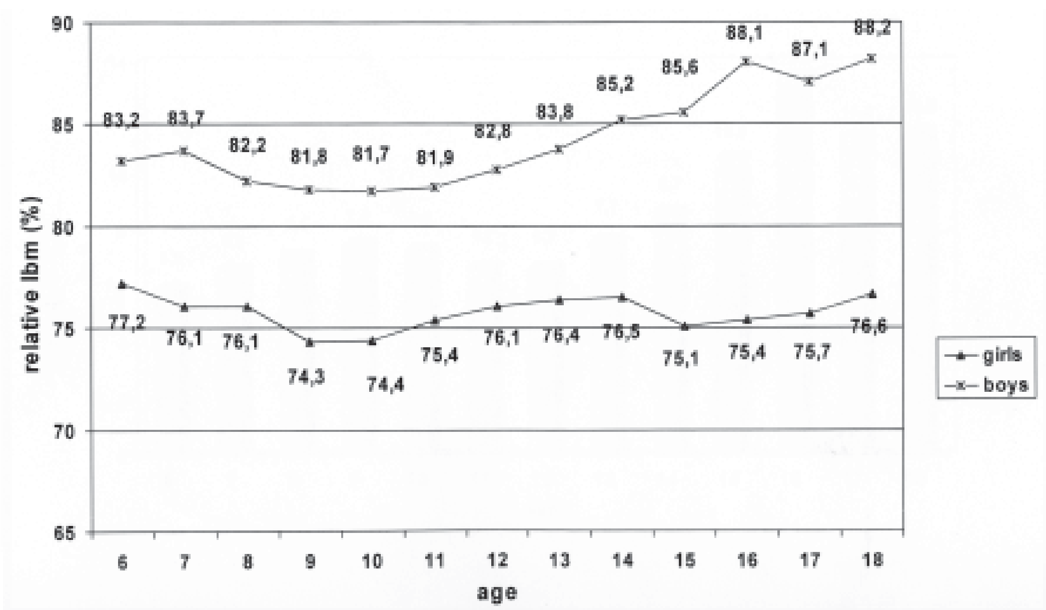

Fig. 2. Relativ lean body mass (%) according to sex during childhood and adolescense

mass in males during puberty and adolescence, while among females, relative fat mass increased only slightly during this phase of life. Furthermore, the marked increase in lean body mass during puberty and adolescence in males is responsible for the increasing mean gender differences in relative lean body mass, because relative lean body mass remained more or less stabile among girls during puberty and adolescence.

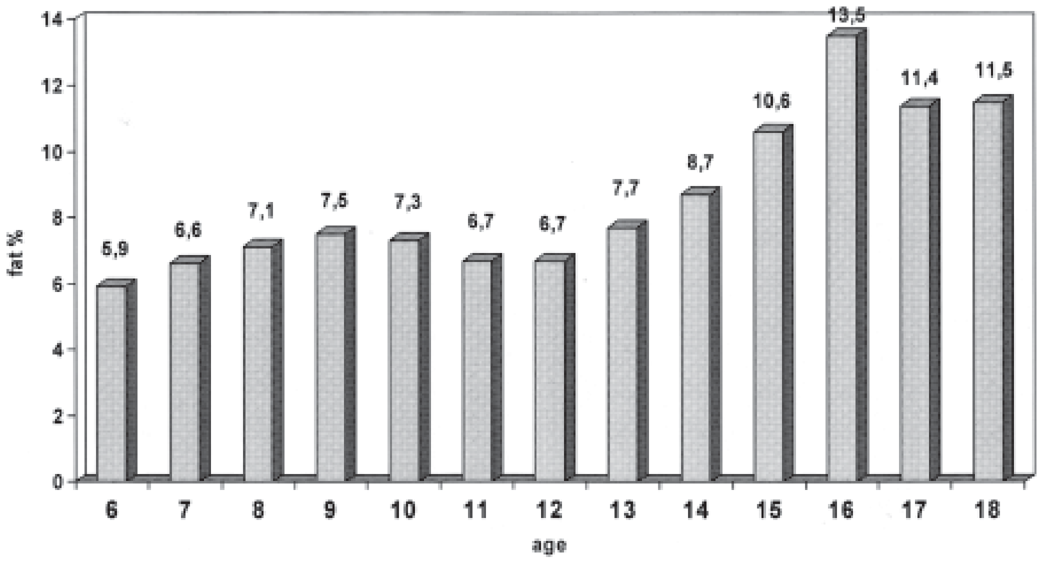

Fig. 3. Average sex difference in fat % by age during childhood and adolescene

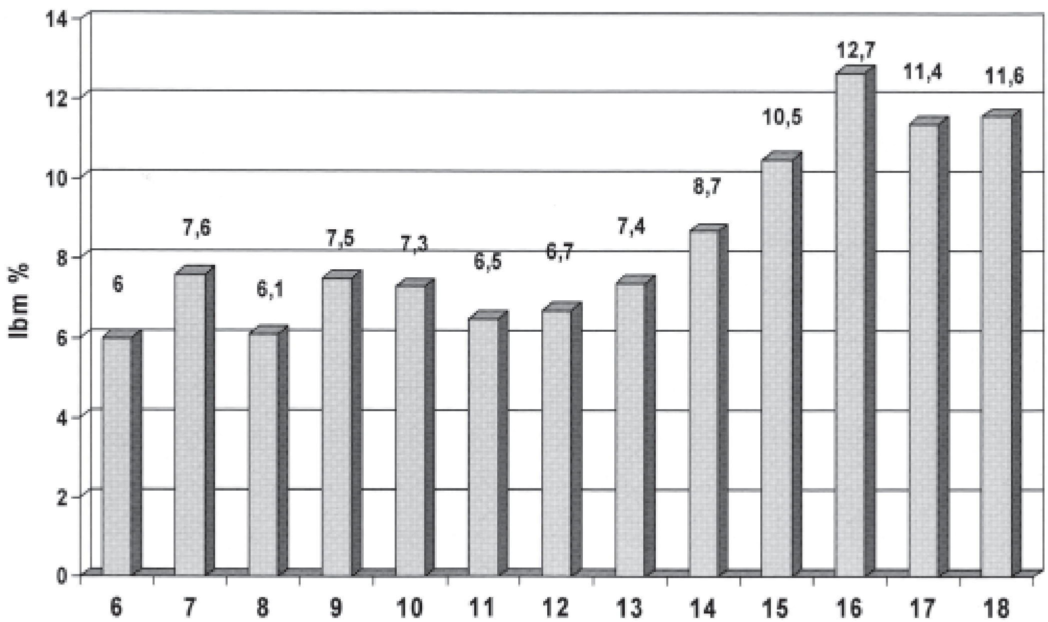

Fig. 4. Average sex difference in lbm % by age during childhood and adolescene

Adulthood

During adulthood males and females differed statistically significantly in relative fat mass and relative lean body mass. Adult females exhibited always a significantly higher amount of relative fat mass ($p < 0.001$) and a significantly lower amount of relative lean body mass ($p < 0.01$) than their male counterparts (see Figs. 5 and 6). The mean gender differences in relative fat mass and

Table 1: Gender differences in weight status according to age

	Underweight BMI < 18.50		*Normal weight BMI 18.50-24.99*		*Overweight BMI 25.00-29.99*		*Obese BMI > 30.00*		
	Male	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*	*Significance*
6 yrs	0.0%	0.0%	71.%	88.9%	14.3%	0.0%	14.3%	11.1%	n.s
7 yrs	4.8%	4.2%	84.0%	70.8%	4.0%	12.5%	8.0%	12.5%	n.s
8 yrs	2.1%	3.7%	83.3%	84.8%	8.3%	3.8%	6.3%	7.7%	n.s
9 yrs	4.0%	4.6%	79.4%	73.4%	9.5%	19.5%	7.1%	2.4%	n.s
10 yrs	5.1%	5.7%	75.8%	72.9%	9.5%	7.1%	9.5	14.3%	n.s
11 yrs	8.6%	10.4%	79.0%	71.8%	7.5%	7.8%	4.9%	10.0%	n.s
12 yrs	6.5%	12.3%	76.1%	74.1%	13.8%	10.0%	3.6%	3.6%	n.s
13 yrs	8.3%	13.9%	72.9%	73.0%	12.0%	8.7%	6.8%	4.3%	n.s
14 yrs	2.7%	10.0%	71.2%	80.0%	6.9%	8.6%	9.2%	1.4%	p<0.05
15 yrs	1.9%	8.7%	77.9%	79.3%	10.8%	4.3%	9.4%	7.6%	p<.0.05
16 yrs	4.5%	8.1%	86.4%	82.4%	4.5%	2.7%	4.5%	6.8%	n.s
17 yrs	0.0%	2.9%	85.7%	88.2%	7.1%	2.6%	7.1%	6.6%	n.s
18 yrs	0.0%	2.5%	91.7%	84.4%	8.3%	4.9%	0.0%	8.2%	n.s
19-29 yrs	0.0%	3.2%	75.0%	72.5%	25.0%	17.2%	0.0%	7.1%	n.s
30-39 yrs	0.0%	3.4%	87.3%	66.7%	12.7%	21.8%	0.0%	8.1%	n.s
40-49 yrs	0.0%	0.5%	67.1%	46.8%	23.5%	38.8%	8.5%	13.9%	n.s
50-59 yrs	0.0%	1.1%	44.4%	44.9%	44.4%	40.4%	11.1%	13.6%	n.s
60-69 yrs	0.0%	1.1%	32.6%	31.8%	58.1%	49.4%	9.4%	17.6%	n.s
70-79 yrs	0.0%	1.6%	39.0%	43.0%	51.6%	45.7%	9.4%	9.7%	n.s
>80 yrs	0.0%	3.9%	71.4%	66.7%	28.6%	17.6%	0.0%	11.8%	n.s

relative lean body mass are stabile upto the 5th decade of life and increased markedly during the 6th decade of life (Figs. 7 and 8). After the 5th decade of life, the mean gender differences decrease and the lowest gender differences are observable for the highest age group (> 80 years). A significant increase in fat mass with increasing age upto the 7th decade of life was found for both genders. Regarding relative lean body mass a significant decrease was observable for both genders starting during the third decade of life.

Gender and Body Composition

The impact of gender on body composition was also tested by linear regression analyses. As to be seen in table 2, gender had an independent effect on body composition during childhood and adolescence as well as during adulthood. The female sex was always associated with a higher amount of relative fat mass, while the male sex was associated with a higher amount of relative lean body mass.

DISCUSSION

Sexual size and shape dimorphism occurs when males and females of a species differ systematically in body size and body shape (Cox and Calsbeek 2009). This phenotypic differences are the result of the process of sex differentiation, which relies on establishment of chromosomal

Table 2: Impact of gender and age on body composition (Linear regression analyses)

	Regression coefficient B	*Significance*	*95% confidence interval*
Children and Adolescents			
Dependent variableRelative fat mass (fat %)			
Gender	7.78	<0.0001	7.02 – 8.53
Age	-0.23	<0.001	-0.36 – -0.09
Dependent variableRelative lean mass (lbm%)			
Gender	-0.78	<0.0001	-8.53 – -7.02
Age	0.23	<0.001	0.09 – 0.36
Adults			
Dependent variableRelative fat mass (fat %)			
Gender	14.01	<0.0001	12.14 – 15.89
Age	0.16	<0.0001	0.13 – 0.19
Dependent variableRelative lean mass (lbm%)			
Gender	-5.03	<0.0001	-6.27 – -3.79
Age	-0.01	n.s.	-0.03 – 0.02

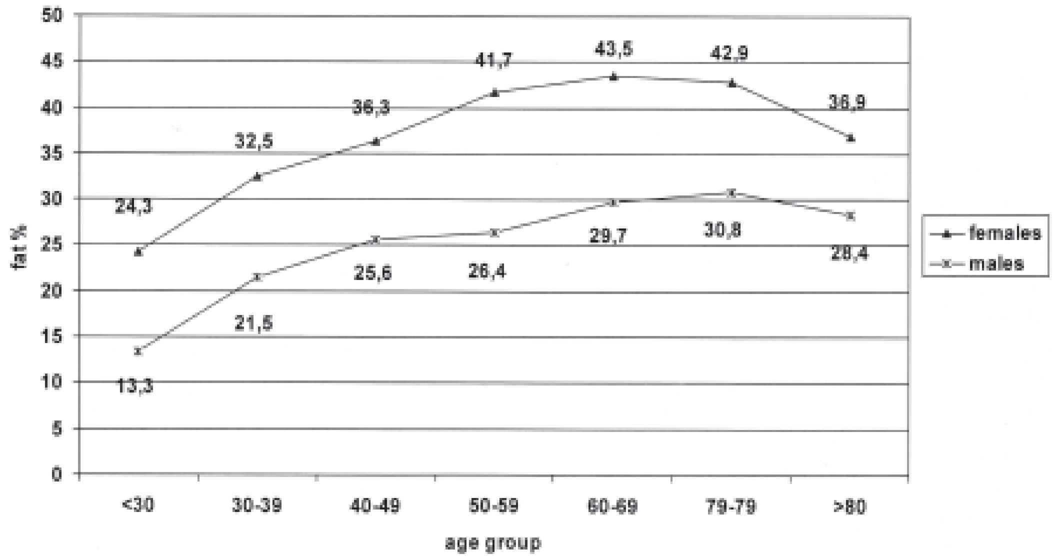

Fig. 5. Relative fas mass (%) according to sex during adulthood

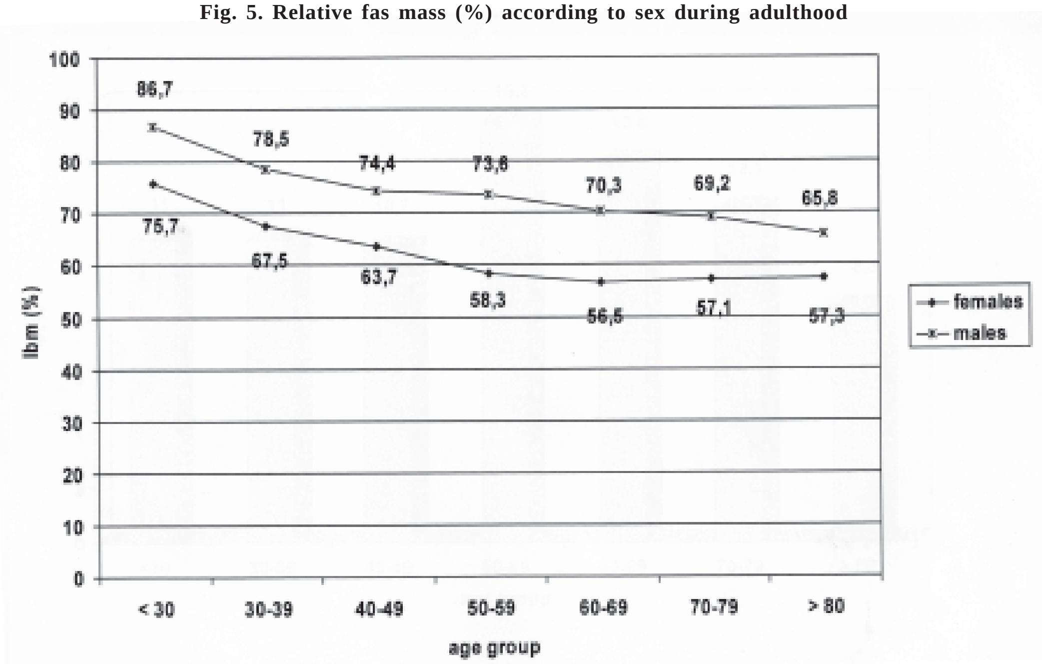

Fig. 6. Relative lean body mass (%) according to sex during adulthood

sex at fertilization, followed by the differentiation of the gonads and ultimately by the development of phenotypic sex during puberty and adolescence (Haqq and Donahoe 1998). Among many species but in particular among humans, males and females differ not only in size and shape, they show also marked differences in body composition. It is well established that adult females surpass males in absolute and relative amount of subcutaneous fat tissue, while males exhibit a quantitative higher amount of fat free body mass including bone as well as soft tissue

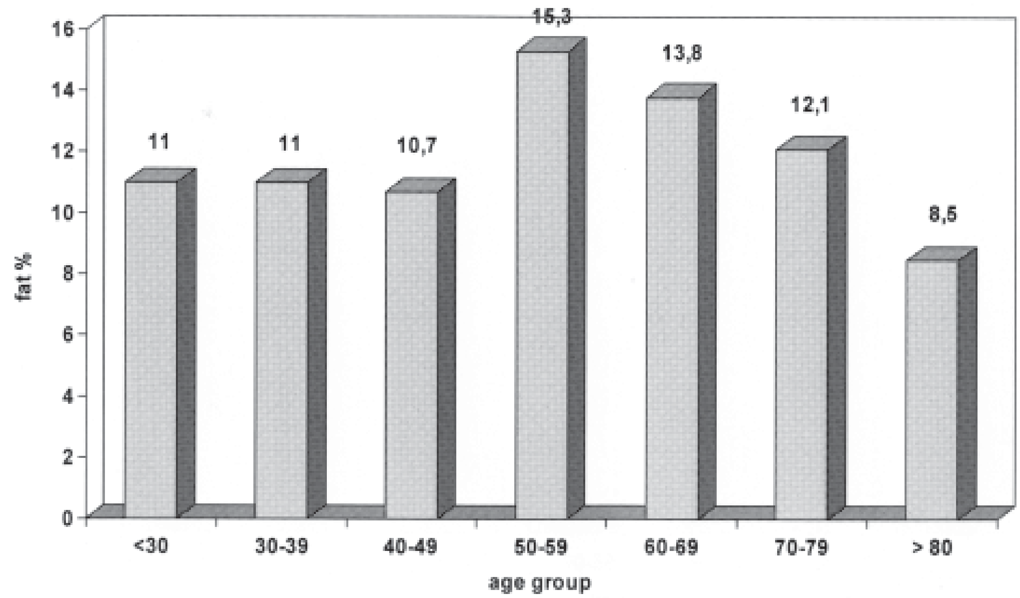

Fig. 7. Average sex difference in fat % by age during adulthood

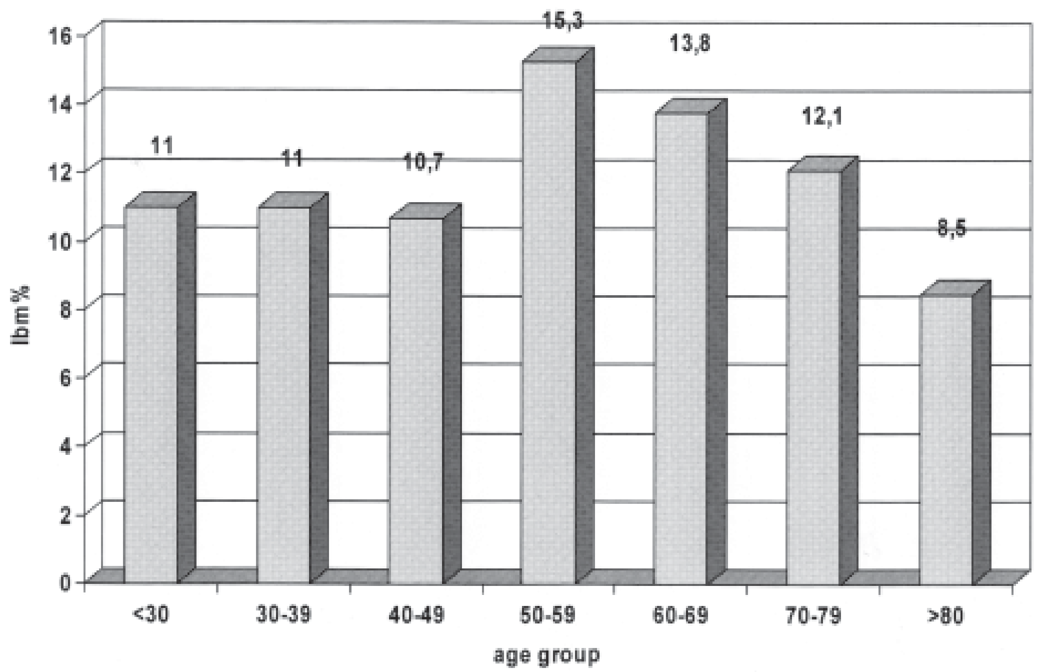

Fig. 8. Average sex difference in LBM % by age during adulthood

lean body mass, i.e. muscle mass throughout adult life (Forbes 1987; Malina et al. 1999; Kyle et al. 2001a,b; Shen et al. 2009). From a physiological point of view, gender differences in body composition can be explained easily by gender typical secretion of sex hormones (Rosenbaum and Leibel 1999; Gatford et al. 1998) and gender typical differences lipid metabolism (Mitendorfer

2005; Magkos and Mittendorfer 2009). Since marked gender differences in sex hormone levels occur not before puberty in postnatal life, gender differences in body composition during prepubertal phase of life were considered to be slight (Forest 1981; Forbes 1987). However, during the last 20 years an increasing number of studies described significant gender differences in body fat and lean body mass even at the ages between 3 and 10 (Faulkner et al. 1993; Nelson et al. 1997; Taylor et al. 1997; Mast et al. 1998; Kirchengast 2002). These findings are in accordance with the results of the present paper. In the present study, girls and boys differed statistically significantly in relative fat mass and lean body mass adjusted for height even during prepubertal phase of life. During puberty, the average gender differences in relative fat mass and relative lean body mass increased. This significant increase was mainly due to the dramatic increase in lean body mass among boys during puberty and adolescence. Girls exhibited a high amount of body fat even during prepuberty, which increased slightly during puberty and adolescence. During adulthood the gender differences in body composition remain stabile up to the fifth decade of life. Then during the sixth decade when females reach postmenopause, the differences increase and decrease not earlier than during the eighth decade of life. These marked gender differences can be explained in a proximate as well as in an ultimate manner. From a proximate or physiological point of view, the observed gender differences in body composition are the result of gender typical differences in sex hormone secretion (Gatford et al. 1998; Rosenbaum and Leibel 1999) and lipid metabolism (Mittendorfer 2005; Magkos and Mittendorfer 2009). These gender differences in sex hormone secretion however occur not earlier than at the onset of puberty. Therefore, we have also to consider ultimate or evolutionary explanations. The well documented sexual dimorphism in stature height (Gustafsson et al. 2007) was discussed as an evolutionary result of male-male competition for mates since a long time (Alexander 1979) comparable the interaction between intrasexual competition and body weight dimorphism in anthropoid primates (Plavcan and van Schaik 1997). The higher amount of muscle mass in males may be interpreted in the same sense as the sexual dimorphism in stature height, as a result of sexual selection. Gender differences in body composition, first of all in body fat, seem to reflect gender typical energetic demands of reproductive physiology. Body fat, in particular subcutaneous fat of the lower body region, represents an important energy store, which enables the female body to bear the energetic costs of pregnancy and lactation (Frisch 1985; Ellison 1990; Kirchengast and Huber 2001). Since a negative energy balance, low fat storages and a low weight status have adverse effects on female reproductive success, gender differences in the amount of body fat may be interpreted as a result of natural selection. Nevertheless one problem remains: During infancy and childhood, the energetic requirements of boys and girls are more or less equal, they differ not in height and weight and girls have not to deal with the energetic costs of successful reproduction. Therefore, the significantly higher amount of relative fat tissue in prepubertal girls may reflect the very early preparation of the female body for future reproductive function. At the beginning of the Third millenium we are also confronted with culture driven changes in the individual acceptance of body shape and body composition. On the one hand culture typical beauty ideals lead to low amounts of body fat among adolescent girls, also expressed in the relatively high prevalence of underweight among 11 to 16 year old girls in the present sample. On the other hand, increased energy intake and improved living conditions of children in contemporary industrialized societies, predominantly of the Western world, result not only in the well known phenomenon of accele-ration, but also enable the female body to store energy deposits as early as possible, even earlier than in any other phase of our evolution and history.

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