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Associations of lifestyle factors with serum dehydroepiandrosterone sulfate and insulin-like growth factor-1 concentration in prepubertal children

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Summary

Objective—Little is known about the relationships of dietary factors, physical activity, and sedentary behavior to dehydroepiandrosterone sulfate (DHEAS) and insulin-like growth factor-1 (IGF-1) concentrations among prepubertal children. Therefore, we studied the associations of these lifestyle factors with serum DHEAS and IGF-1 in children.

Design and subjects—Cross-sectional analysis of a population sample of 431 prepubertal children aged 6-9 years.

Measurements—Assessment of dietary factors by food records and physical activity and sedentary behavior by a combined heart rate and movement monitor and a questionnaire. Measurement of serum DHEAS and IGF-1.

Results—Consumption of low-fiber grain products (standardized regression coefficient β=0.118, *P*=0.017) and intake of vegetable protein (β=0.100, *P*=0.045) were positively and consumption of sugar-sweetened beverages (β=-0.117, *P*=0.018) was inversely associated with DHEAS after adjustment for sex, age, and body fat percentage. Energy intake (β=0.160, P=0.001) was positively associated with IGF-1 adjusting for sex, age, and body fat percentage. Vigorous physical activity was inversely associated with DHEAS after adjustment for sex and age (β=-0.120, *P*=0.027), and total (β=-0.137, *P*=0.007), moderate (β=-0.130, *P*=0.012), vigorous (β=-0.136, *P*=0.011), and moderate to vigorous physical activity (β=-0.160, P=0.003) were inversely and total sedentary behavior (β=0.151, *P*=0.003) was positively associated with IGF-1 adjusting for sex and age. None

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of physical activity measures was associated with DHEAS or IGF-1 after additional adjustment for body fat percentage.

Conclusions—Lifestyle factors have weak and moderate associations with biochemical markers of adrenarche in prepubertal children. These associations indicate body fat independent and dependent influences of diet and physical activity, respectively.

Keywords

DHEAS; IGF-1; Body fat percentage; Lean body mass; Lifestyle factors

Introduction

Adrenarche is a gradually developing process of the adrenal cortex leading to increased production of androgen precursors, mainly dehydroepiandrosterone (DHEA) its sulfate (DHEAS), and androstenedione (1). These weak androgens are converted peripherally to more potent androgens, testosterone and dihydrotestosterone, leading to clinical signs of adrenarche, including adult type body odor, oily hair, acne or comedones, pubic or axillary hair, and increased statural growth (2).The timing of adrenarche varies widely between children and appears to be influenced by prenatal and postnatal factors (3). In turn, the biochemical markers of adrenarche have been associated with earlier age at menarche (4).

The weight-adjusted heritability of adrenal androgen secretion is high, but also environmental factors play a role (5). The association of adiposity with adrenarche has been shown in several studies (6–8). Body fat percentage was found to correlate positively with serum DHEAS concentration (9), and body mass index (BMI) change was observed to correlate positively with urinary excretion of DHEAS in children (10). Furthermore, we showed recently that adiposity increased the likelihood of clinical signs of adrenarche in a population sample of children aged 6-9 years (11).

Prepubertal children with premature adrenarche have been found to have elevated serum IGF-1 levels (12). IGFs and their receptors are expressed in human adrenal cortex (13, 14), and IGF-1 can increase adrenal androgen production (15). However, there is no evidence that IGF-1 would directly increase adrenocortical androgen production during adrenarche (14).

Increased dietary intake of vegetable protein and fiber have been associated with decreased gonadal estradiol production in pubertal girls independent of body size (16). However, there are only few studies on the associations of dietary factors with adrenal androgen metabolism in children. In one previous study, a higher intake of dietary animal protein was associated with a higher urinary excretion of C19 steroid metabolites that was used as a marker of adrenal androgen secretion (7). Interestingly, some animal studies suggest that the administration of DHEA decreases the intake of food containing large amounts of fat in lean and obese rats (17). This effect was mediated by hypothalamic neurotransmitters (18). Moreover, a higher intake of protein(19, 20), animal protein (19, 21), and energy (20), a lower intake of fat, monounsaturated fat, and polyunsaturated fat (19), and a higher

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consumption of milk (21, 22) have been related to a higher serum IGF-1 concentration in healthy children.

The results of some earlier studies suggest that increased physical activity is associated with decreased serum testosterone levels in boys independent of BMI (23). We are not aware of any published reports on the association of physical activity or sedentary behavior with serum or urinary adrenal androgen levels in children. However, there is some evidence that a single bout of exercise increases serum IGF-1 concentration (24) but that exercise training during negative energy balance or heavy training decreases serum IGF-1 concentrations in children and adults (24–26). There is no evidence on the association between sedentary behavior and serum IGF-1 concentration in children.

Little is known about the associations of dietary factors, physical activity, and sedentary behavior with serum DHEAS and IGF-1 concentrations among prepubertal children independent of body composition. We therefore examined these relationships in a population sample of children aged 6-9 years.

Subjects and Methods

Study population

These analyses are based on data from the baseline examinations of the Physical Activity and Nutrition in Children (PANIC) Study which is an ongoing controlled physical activity and dietary intervention study in a population sample of primary school children from the city of Kuopio in Finland (27).

Altogether 736 children aged 6-9 years from 16 schools of the city of Kuopio were invited to participate in the study. Of them, 512 (70 %) participated in the baseline examinations in 2007-2009. The participants did not differ in age, sex distribution, or BMI standard deviation score (BMI-SDS) from all children who started the first grade in the primary schools of Kuopio in 2007–2009 based on comprehensive data obtained from school health examinations. The exclusion criteria for the analyses were central puberty and long-term medication that could have an effect on growth or adrenal function. Data on food consumption were available for 395 children (190 girls, 205 boys) and data on physical activity and sedentary behavior for 431 children (207 girls, 224 boys). The study was conducted according to the guidelines laid down in the Declaration of Helsinki. The study protocol was approved by the Research Ethics Committee of the Hospital District of Northern Savo. All children participating in the study and their parents gave their informed written consent.

Assessment of pubertal signs, DHEAS, and IGF-1

Central gonadotropin-dependent puberty was defined by clinical examination as breast development at Tanner stage ≥2 for girls and testicular volume ≥4 mL assessed using an orchidometer for boys.

All serum samples were taken after an overnight fast and kept deep frozen until they were analyzed. Serum DHEAS concentrations were determined using an enzyme-linked immunosorbent assay ELISA kit (Alpha Diagnostic International, San Antonio, TX). The intra-assay coefficient of variation (CV) of the DHEAS method was 7.5-11.5% and the inter-assay CV was 7.0-11.0%. Serum IGF-1 concentrations were determined using an ELISA kit (Mediagnost, Reutlingen, Germany). The intra-assay CV of the IGF-1 method was 5.1-6.6% and the inter-assay CV was 7.7-9.2%. We defined biochemical adrenarche as serum DHEAS concentration ≥ 40 μg/dL (1.08 μmol/L) (28) and premature adrenarche as biochemical adrenarche with any clinical sign of adrenarche (adult type body odor, oily hair, acne or comedones, or pubic or axillary hair) before eight years in girls and nine years in boys (2).

Assessment of body size and composition

Body weight was measured twice after an overnight fast, bladder emptied, and standing in light underwear by InBody ®720 bioelectrical impedance device (Biospace Co. Ltd., Seoul, Korea) to accuracy of 0.1 kilograms. The mean of the two values was used in the analyses. Body height was measured three times in the Frankfurt plane without shoes using a wall-mounted stadiometer to accuracy of 0.1 centimeter. The mean of the two nearest values was used in the analyses. BMI was calculated as body weight (kg) divided by body height (m) squared. Height standard deviation score (Height- SDS), BMI-SDS, and the prevalence of overweight were calculated according to the Finnish growth references (29). Body fat percentage and lean body mass (kg) were measured bladder emptied and lying in light clothing by the Lunar dual-energy X-ray absorptiometry (DXA) device (Lunar Prodigy Advance; GE Medical Systems, Madison, WI). Information on gestational age at birth, birth weight, and birth length were obtained from Kuopio University Hospital records.

Assessment of dietary factors

Eating frequency, food consumption, and total energy and nutrient intakes were assessed by food records of either consecutive four days, including at least one weekend day (91.6%), or consecutive three days, including at least one weekend day (8.4%). A clinical nutritionist instructed the parents to record all food and drinks consumed by their child at home, at school, in afternoon care, and elsewhere outside home using household or other measures, such as tablespoons, deciliters, and centimeters, in person at the first study visit (27). The parents were instructed to report the recipes of mixed dishes and the brands and the contents of food products. A clinical nutritionist reviewed the food records with the parents at the second study visit and completed the records using a picture booklet of portion sizes. Moreover, a clinical nutritionist asked the catering company about the details of food and drinks, such as menus, cooking fat, and spread on bread, served at schools and in afternoon care. All prepared foods and mixed dishes were disaggregated into ingredients according to the recipes used. Meals were defined according to the recorded time and type of food and were classified as breakfast, lunch, and dinner, and all eating and drinking occasions between the meals were classified as snacks. We analysed food consumption and nutrient intake using The Micro Nutrica dietary analysis software, version 2.5 (The Social Insurance Institution of Finland), that uses Finnish and international data on the nutrient compositions of foods (30). A clinical nutritionist also updated the software by adding new food items and products with their precise nutrient content received from the producers.

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Assessment of physical activity and sedentary behavior

Physical activity and sedentary behavior were assessed by a combined heart rate and movement monitor (Actiheart, CamNtech, Cambridge, UK) for four consecutive days without interruption (31). The monitor was attached on the chest with two standard electrocardiogram electrodes (Bio Protech Inc, Korea). The monitor was set to record in 60-second epochs. Upon retrieving the monitoring device, heart rate data were first cleaned, then individually calibrated with parameters from the cycle test and combined with trunk acceleration using branched equation modeling to produce intensity time-series. Whilst minimizing diurnal bias caused by any potential non-wear episodes, physical activity energy expenditure was calculated by time-integration of the intensity time-series, and the time distribution of activity intensity was generated by using standard metabolic equivalents (METs). For these analyses, the equivalent of 3.5ml O2/min/kg (71 J/min/kg) was used to define 1 MET, and data were summarized as sedentary behavior (≤1.5 METs), light physical activity (>1.5-4 METs), moderate physical activity (>4-7 METs), and vigorous physical activity (>7 METs). Sedentary behavior was calculated by subtracting sleep from total time of ≤1.5METs. Physical activity records were included in the analysis if they contained ≥48h wear data.

Physical activity and sedentary behavior were also assessed by the PANIC Physical Activity Questionnaire filled out by the parents (32). Total daily amounts of physical activity and sedentary behavior were calculated in minutes per day. Types of physical activity included unsupervised physical activity, organized sports, organized exercise other than sports, commuting to and from school, and physical activity during recess. All children in the first grade had 90 minutes of physical education per week at school which was included in total physical activity. Types of sedentary behavior included screen-based sedentary behavior (watching television and videos, using the computer and playing video games, using a mobile phone and playing mobile games), sedentary behavior related to academic skills (reading, writing), sedentary behavior related to music (listening to music, playing a musical instrument), sedentary behavior related to arts, crafts, and games (drawing, doing arts and crafts, playing board and card games), and sitting and lying for a rest.

Statistical methods

The SPSS statistical analysis software, Version 21.0 (IBM Corp., Armonk, NY), was used for statistical analyses. We analyzed the correlations between body fat percentage, lean body mass, and serum DHEAS and IGF-1 concentrations in all children and separately in girls and boys using the non-parametric Spearman`s rank order correlation test. For parametric tests, we natural logarithm transformed serum DHEAS and IGF-1 concentrations to normalize their skewed distributions. We analyzed the associations of dietary factors, physical activity, and sedentary behavior with serum DHEAS and IGF-1 concentrations by linear regression analysis adjusted for sex and age (Model 1) and additionally for body fat percentage (Model 2) or for lean body mass (Model 3). We performed logistic regression analyses adjusted for sex, age, and body fat percentage to explore whether dietary factors, physical activity, and sedentary behavior were associated with the risk of having serum DHEAS concentration ≥ 40 μg/dL (1.08 μmol/L) that has been suggested as definition for biochemical adrenarche (28). Associations with $P < 0.05$ were considered statistically significant.

Results

The characteristics of children are shown in Table 1. The median age of the children was 7.6 years. Almost all children (95%) were born full term and appropriate for gestational age and their median birth weight was 3590 g. Altogether 56 children (13%) were overweight or obese. Biochemical adrenarche indicated by serum DHEAS concentration ≥ 40 μg/dL (1.08 μmol/L) was present in 65 children (15%, 29 girls and 36 boys) and 16 children (4%) had premature adrenarche.

Correlations between serum DHEAS, serum IGF-1, body fat percentage, and lean body mass

Body fat percentage correlated positively with serum DHEAS concentration in all children (Table 2), girls (Spearman's correlation coefficient rho=0.157, P=0.025), and boys (rho=0.180, P=0.008). Lean body mass also correlated positively with serum DHEAS concentration in all children (Table 2), girls (rho=0.264, P<0.001), and boys (rho=0.148, P=0.029). Serum IGF-1 concentration correlated positively with serum DHEAS concentration in all children (Table 2) and girls (rho=0.238, P=0.001) but not boys (rho=0.106, P=0.114). Body fat percentage correlated positively with serum IGF-1 concentration in all children (Table 2), girls (rho=0.210, P=0.003) and boys (rho=0.406, P<0.001), and again similar directions of correlations were observed for lean body mass and serum IGF-1 concentration in all children (Table 2), girls (rho=0.355, P<0.001), and boys (rho=0.269, P<0.001).

Associations of dietary factors with serum DHEAS and IGF-1 concentrations

A higher consumption of low-fiber grain products was associated with a higher serum DHEAS concentration after adjustment for sex and age and after additional adjustment for body fat percentage or lean body mass (Table 3). A lower consumption of sugar-sweetened beverages was related to a higher serum DHEAS concentration after adjustment for sex, age, and body fat percentage or for sex, age, and lean body mass (Table 3). A higher intake of vegetable protein was associated with a higher serum DHEAS concentration after adjustment for sex, age, and body fat percentage (Table 3).

A higher energy intake was related to a higher serum IGF-1 concentration after adjustment for sex and age and after further adjustment for body fat percentage (Table 3).

Associations of physical activity and sedentary behavior with serum DHEAS and IGF-1 concentrations

A lower level of objectively assessed vigorous physical activity was associated with a higher DHEAS after adjustment for sex and age and after additional adjustment for lean body mass (Table 4). Sedentary behavior was not associated with DHEAS (Table 4).

A lower level of objectively assessed total physical activity was associated with a higher serum IGF-1 concentration after adjustment for sex and age and after additional adjustment for lean body mass (Table 4). Lower levels of objectively assessed moderate, vigorous, and moderate to vigorous physical activity were associated with a higher serum IGF-1 concentration after adjustment for sex and age and after additional adjustment for lean body mass (Table 4). Higher levels of awake-time sedentary behavior assessed objectively or by a questionnaire were associated with a higher IGF-1 after adjustment for sex and age and after additional adjustment for lean body mass (Table 4). A higher level of sedentary behavior related to arts, crafts, and games was associated with a higher serum IGF-1 concentration after adjustment for sex, age, and lean body mass (Table 4).

Associations of dietary factors, physical activity, and sedentary behavior with the risk of having serum DHEAS concentration ≥ 40 μg/dL (1.08 μmol/L)

Eating frequency, food consumption, nutrient intake, physical activity, or sedentary behavior was not associated with the risk of having serum DHEAS concentration ≥ 40 μg/dL (data not shown).

Discussion

Our study in a population sample of prepubertal children showed that a higher consumption of low-fiber grain products, a lower consumption of sugar- sweetened beverages, a higher intake of vegetable protein, and a lower level of vigorous physical activity were related to a higher serum DHEAS concentration after controlling for body fat percentage. A higher energy intake, lower levels of total, moderate, vigorous, and moderate-to-vigorous physical activity, and a higher level of total sedentary behavior were associated with a higher serum IGF-1 concentration.

We found positive correlations of body fat percentage and lean body mass with serum DHEAS concentration that is in line with the results of a previous report (9). Our observation is also consistent with the notion that the timing of adrenarche is more advanced in children who experience faster postnatal growth (3). Moreover, we found that serum DHEAS concentration was positively correlated with serum IGF-1 concentration in girls but not in boys, which is also consistent with the results of earlier studies (33, 34). We showed recently that prepubertal girls are more likely to have clinical signs of androgen action than prepubertal boys (11). Courant and coworkers (35) showed that prepubertal girls have higher circulating levels of androgen metabolites than boys. Aromatizable androgens converted to estrogens are capable to stimulate the growth hormone - IGF-1 axis (36). Thus, it is possible that DHEAS through its conversion products stimulates growth hormone and IGF-1 production more in girls than in boys. These observations may explain the positive correlation between serum DHEAS and IGF-1 concentration in girls but not in boys.

To our knowledge, there are no published reports on the relationships of dietary factors with serum DHEAS concentration. Such associations could arise by at least two different mechanisms: dietary factors may have an effect on the hypothalamo-pituitary-adrenal axis or adrenal androgens may affect food intake through hypothalamic neurotransmitters, which mechanism has been shown in animal models (17, 18). There is only one report on the

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association of nutrient intake with adrenal androgen secretion among prepubertal children (7). In this study, a higher intake of dietary animal protein was related to a higher urinary excretion of C19 steroid metabolites that were used as a marker of adrenal androgen secretion (7). We found moderate associations of a higher consumption of low-fiber grain products, a lower consumption of sugar sweetened beverages, and a higher intake of vegetable protein with a higher serum DHEAS concentration. However, we did not observe any association of animal protein intake with serum DHEAS concentration in our population sample of children. This inconsistency may be explained by the different methods used in the evaluation of adrenal androgen secretion or food cultures in the study populations, and as the findings in these two are not consistent with each other, it is possible that apart from affecting body fat content, diet has no major effects on adrenocortical function. To study this further, a controlled study on modulated diet should be conducted. Further, if DHEA(S) affects food intake also in humans, a trial on the effect of DHEA substitution on food intake would be interesting.

The associations of dietary factors with serum IGF-1 concentration is of interest as IGF-1 may mediate some of the effects of diet on growth and health. Rogers and coworkers (19) observed that a higher intake of energy, total protein and animal protein and a lower intake of total fat, monounsaturated fat, and polyunsaturated fat but not measures of food consumption were associated with higher serum IGF-1 concentration in children aged seven to eight years. However, a higher consumption of fruit was related to a higher serum IGF-1 concentration among boys. Similarly, in some other studies a higher intake of energy (20), total protein (20), and animal protein (21) and, a higher consumption of milk (21, 22) have been related to a higher serum IGF-1 concentration in children. We found that a higher energy intake but not eating frequency, energy-adjusted food consumption, or nutrient intake was associated with higher serum IGF-1 levels in children. However, it is difficult to compare the results of these studies with different age ranges and numbers of participants, because the age of children affects dietary intake and serum IGF-1 levels and a small number of children may have lead in false positive findings. It is also possible that some of the inconsistent results in these studies are explained by differences in food cultures, such as sources of animal and vegetable protein, in the study populations.

Acute physical exercise seems to increase circulating DHEA and DHEAS, whereas the effects of exercise training on these have been contradictory in adults (37). However, there are no previous reports on the association of physical activity or sedentary behavior with serum DHEAS concentration in children. We observed that a lower level of vigorous physical activity but not less intensive physical activity or sedentary behavior was associated with a higher serum DHEAS concentration. However, the relationship between vigorous physical activity and DHEAS levels weakened after controlling for body fat percentage but not lean body mass. The explanation for this finding is that body fat percentage is associated not only with DHEAS concentration but also vigorous physical activity (38).

A single bout of exercise has been found to increase serum IGF-1 concentration (24). The reason for this may be a release of IGF-1 from skeletal muscle or from IGF binding proteins. On the contrary, exercise training during negative energy balance or heavy training may decrease serum IGF-1 levels in children (24–26) by decreasing liver IGF-1 production (24).

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Exercise training may also increase the levels of inflammatory cytokines which can inhibit IGF-1 production (26). However, there are no published reports on the association of physical activity or sedentary behavior with serum IGF-1 concentration in population samples of children. We found that a higher level of moderate-to-vigorous physical activity and a lower level of sedentary behavior were associated with a lower serum IGF-1 concentration in children. These associations were largely explained by body fat percentage that has previously been positively correlated with serum IGF-1 concentration in children (9). However, controlling for lean body mass had less effect on these relationships that may be explained by its weaker association with IGF-1 level in our study and an earlier study (9).

The strengths of this study include a relatively large population sample of prepubertal children, the assessment of dietary factors by food records that were checked individually by a clinical nutritionist, the objective assessment of physical activity and sedentary behavior including intensity classification by individually calibrated combined heart rate and movement monitoring, the detailed assessment of different types of physical activity and sedentary behavior by a questionnaire, and the accurate assessment of body fat percentage by DXA. A limitation of the study is that, although guided carefully, food consumption was assessed using food records reported by the parents, which may have caused misreporting.

Our study provides new information on the associations between lifestyle factors and adrenarche, which typically occurs before the onset of puberty (39). Although adiposity plays a major role in the development of adrenarche, our results show that dietary factors, physical activity, and sedentary behavior have weak to moderate associations with serum DHEAS and IGF-1 levels in prepubertal children. The associations of dietary factors and serum DHEAS and IGF-1 levels tend to be partly independent of body fat percentage whereas those of physical activity and sedentary behavior seem to be explained by adiposity. However, based on this and several previous studies, the most effective way to control adrenal androgen secretion is to prevent overweight.

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Table 1

Characteristics of children

	Median	Interquartile range	Range
Age, years	7.6	7.4-7.9	6.6-8.9
Body height, cm	129.0	125.2-132.0	110.7-144.7
Body height-SDS[a]	0.1	-0.6-0.8	-2.8-3.1
Body weight, kg	25.9	23.4-29.0	15.2-51.4
BMI-SDS[a]	-0.2	-1.0-0.5	-3.5-2.4
Body fat percentage	18.7	13.3-23.8	5.4-44.8
Lean body mass, kg	20.4	18.9-22.2	13.3-28.1
Gestational age at birth, wk	40	39-40	32-42
Birth length, cm	50.0	49.0-51.0	40.5-56.0
Birth weight, g	3590	3203-3880	1595-5090
Serum DHEAS, µmol/L	0.57	0.32-0.84	0.01-7.84
Serum IGF-1, nmol/L	22.1	17.8-26.8	7.76-52.1
Eating frequency			
Meals	2.8	2.5-3.0	1.8-3.0
Snacks	2.5	2.0-3.3	0.3-8.0
Food consumption			
Red meat, g/MJ	11.1	7.8-14.7	0.4-39.7
Poultry, g/MJ	1.6	0.0-3.9	0.0-21.6
Fish, g/MJ	0.8	0.0-3.6	0.0-16.2
Low-fiber grain products (fiber < 5 %), g/MJ	15.5	11.8-20.4	0.4-66.2
High-fiber grain products (fiber ≥ 5 %), g/MJ	8.5	5.1-12.6	0.0-42.5
Low-fat milk and sour milk products (fat < 1 %), g/MJ	59.1	14.6-89.9	0.0-192.3
High-fat milk and sour milk products (fat ≥ 1 %), g/MJ	28.3	15.4-55.7	0.0-169.0
Cheese, g/MJ	1.7	0.6-3.1	0.0-11.7
Butter, g/MJ	0.4	0.1-1.4	0.0-6.3
Vegetable oil and oil-based margarine, g/MJ	1.9	1.1-3.0	0.0-8.8
Vegetables (excluding potato), g/MJ	13.6	8.5-19.1	0.9-61.4

	Median	Interquartile range	Range
Potatoes, g/MJ	10.1	6.3-14.5	0.0-43.3
Berries and fruit, g/MJ	13.5	6.6-21.4	0.0-73.0
Sugar-sweetened beverages, g/MJ	15.6	6.5-30.1	0.0-103.3
Sweets and chocolate, g/MJ	3.7	1.7-6.1	0.0-19.6
Nutrient intake			
Energy, MJ/day	6.8	6.0-7.8	3.0-10.9
Protein, E%	16.7	15.0-18.4	9.5-25.4
Vegetable protein, E%	4.2	3.7-4.8	2.3-11.2
Animal protein, E%	12.3	10.5-13.8	4.1-21.7
Fat, E%	29.9	26.4-33.6	16.1-44.7
Saturated fat, E%	12.1	10.2-14.2	5.0-19.4
Monounsaturated fat, E%	9.8	8.7-11.3	5.0-18.3
Polyunsaturated fat, E%	4.7	4.0-5.6	1.9-10.9
Carbohydrates, E%	51.5	48.3-55.2	36.3-66.9
Sucrose, E%	12.5	10.3-14.8	0.6-24.5
Fiber, g/MJ	2.0	1.7-2.5	0.7-4.1
Physical activity assessed objectively			
Total physical activity, min/day	660.8	561.3-719.9	169.3-905.4
Light physical activity, min/day	527.8	442.6-584.7	151.0-766.7
Moderate physical activity, min/day	81.4	57.3-114.6	9.9-300.9
Vigorous physical activity, min/day	17.2	6.4-35.8	0.0-132.1
Moderate to vigorous physical activity, min/day	103.4	71.4-152.1	9.9-326.3
Physical activity assessed by questionnaire			
Total physical activity, min/day	107.9	77.1-140.7	31.4-247.1
Unsupervised physical activity, min/day	42.9	25.7-68.6	0.0-107.1
Organized sports, min/day	0.0	0.0-12.9	0.0-51.4
Organized exercise other than sports, min/day	8.6	0.0-17.1	0.0-124.3
Commuting to and from school, min/day	20.0	10.0-40.0	0.0-180.0
Physical activity during recess, min/day	20.0	20.0-30.0	10.0-30.0
Sedentary behavior assessed objectively			

	Median	Interquartile range	Range
Awake-time sedentary behavior, min/day	660.8	562.9-719.7	169.3-869.8
Sedentary behavior assessed by questionnaire			
Total sedentary behavior, min/day	196.4	143.6-263.6	19.3-666.4
Screen-based sedentary behavior, min/day	98.6	66.4-128.6	0.0-314.3
Sedentary behavior related to academic skills, min/day	25.7	5.7-45.7	0.0-180
Sedentary behavior related to music, min/day	0.0	0.0-25.7	0.0-205.7
Sedentary behavior related to arts, crafts, and games, min/day	45.7	0.0-77.1	0.0-295.7
Sitting and lying for a rest, min/day	0.0	0.0-5.7	0.0-162.9

DHEAS = dehydroepiandrosterone sulfate, IGF-1 = insulin-like growth factor-1, E% = percentage of total energy intake, SDS = standard deviation score

[a]Height and BMI standard deviation scores based on Finnish reference (29).

Number of children (n) varies from 376 to 431 in different variables:
n= 420: Body fat percentage, Lean body mass
n= 428: Gestational age at birth, Birth weight
n= 421: Birth length
n= 395: Eating frequency, Food consumption, Nutrient intake
n= 430: Physical activity during recess
n= 376: Light physical activity, Moderate physical activity, Vigorous physical activity; objectively measured
n= 374: Awake-time sedentary behavior; objectively measured

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Table 2

Correlations between serum DHEAS, serum IGF-1, body fat percentage, and lean body mass

	Serum IGF-1, nmol/L	Body fat percentage	Lean body mass, kg
Serum DHEAS, µmol/L	0.160 (*P*=0.001)	0.155 (*P*=0.001)	0.197 (*P*<0.001)
Serum IGF-1, nmol/L		0.363 (*P*<0.001)	0.172 (*P*<0.001)
Body fat percentage			0.103 (*P*=0.034)

Data are correlation coefficients (*P*-values) from Spearman´s rank order correlation test.

DHEAS = dehydroepiandrosterone sulfate, IGF-1 = insulin-like growth factor-1

Table 3

Associations of dietary factors with serum DHEAS and IGF-1 concentrations

	DHEAS, µmol/L			IGF-1, nmol/L		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Eating frequency						
Meals[a]	0.026	0.054	0.026	-0.053	0.004	-0.030
Snacks[b]	-0.046	-0.048	-0.045	-0.027	-0.045	-0.041
Food consumption						
Red meat, g/MJ	-0.013	-0.032	-0.016	0.019	-0.008	0.013
Poultry, g/MJ	-0.076	-0.084	-0.071	0.036	0.020	0.044
Fish, g/MJ	0.050	0.054	0.051	0.028	0.033	0.028
Low-fiber grain products (fiber <5 %), g/MJ	**0.100** *	**0.118** *	**0.107** *	-0.022	0.000	-0.012
High-fiber grain products (fiber ≥5 %), g/MJ	0.046	0.037	0.036	-0.053	-0.074	-0.083
Low-fat milk and sour milk products (fat <1 %), g/MJ	0.082	0.066	0.057	0.008	-0.016	-0.048
High-fat milk and sour milk products (fat ≥1 %), g/MJ	-0.083	-0.063	-0.048	0.009	0.030	0.077
Cheese, g/MJ	0.033	0.031	0.026	0.055	0.024	0.003
Butter, g/MJ	-0.057	-0.063	-0.061	-0.004	0.008	0.018
Vegetable oil and oil-based margarine, g/MJ	0.030	0.035	0.038	-0.049	-0.055	-0.049
Vegetables (excluding potato), g/MJ	0.018	0.011	0.004	0.071	0.064	0.048
Potatoes, g/MJ	-0.038	-0.043	-0.034	-0.006	-0.019	-0.006
Berries and fruit, g/MJ	-0.010	-0.011	-0.022	0.010	0.019	0.002
Sugar-sweetened beverages, g/MJ	-0.096	**-0.117** *	**-0.105** *	-0.020	-0.034	-0.014
Sweets and chocolate, g/MJ	-0.043	-0.034	-0.049	-0.013	0.001	-0.024
Nutrient intake						
Energy, MJ/day	0.023	0.014	-0.023	**0.149** **	**0.160** **	0.090
Protein, E%	0.035	0.022	0.031	0.091	0.059	0.066
Vegetable protein, E%	0.084	**0.100** *	0.084	-0.022	-0.013	-0.044
Animal protein, E%	0.000	-0.020	-0.004	0.090	0.057	0.075
Fat, E%	-0.053	-0.055	-0.042	-0.031	-0.034	-0.005
Saturated fat, E%	-0.078	-0.078	-0.065	-0.020	-0.019	0.011

	DHEAS, μmol/L			IGF-1, nmol/L		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Monounsaturated fat, E%	-0.051	-0.051	-0.033	-0.044	-0.055	-0.018
Polyunsaturated fat, E%	0.066	0.069	0.069	-0.029	-0.029	-0.027
Carbohydrates, E%	0.036	0.045	0.028	-0.014	0.004	-0.027
Sucrose, E%	-0.041	-0.045	-0.044	-0.019	-0.017	-0.016
Fiber, g/MJ	0.087	0.092	0.082	-0.012	-0.013	-0.033

Data are standardized regression coefficients from linear regression models adjusted for sex and age (Model 1) and additionally for body fat percentage (Model 2) or lean body mass (Model 3). DHEAS = dehydroepiandrosterone sulfate, IGF-1 = insulin-like growth factor-1, E% = percentage of total energy intake

*$P < 0.05$, **$P < 0.01$. Associations with $P < 0.05$ are bolded.

[a]Meals coded as 0 = less than three main meals daily, 1= three main meals daily

[b]Snacks coded as 0 = ≤2 snacks/day, 1 = >2 snacks/day

Table 4

Associations of physical activity and sedentary behavior with serum DHEAS and IGF-1 concentrations

	DHEAS, μmol/L			IGF-1, nmol/L		
	Model 1	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
Physical activity assessed objectively						
Total physical activity, min/day	-0.021	0.046	0.001	**-0.137** **	-0.035	**-0.098** *
Light physical activity, min/day	0.032	0.071	0.050	-0.077	-0.010	-0.040
Moderate physical activity, min/day	-0.071	-0.011	-0.050	**-0.130** *	-0.049	**-0.112** *
Vigorous physical activity, min/day	**-0.120** *	-0.075	**-0.121** *	**-0.136** *	-0.040	**-0.129** *
Moderate to vigorous physical activity, min/day	-0.103	-0.038	-0.086	**-0.160** **	-0.060	**-0.142** **
Physical activity assessed by questionnaire						
Total physical activity, min/day	-0.026	0.002	-0.048	-0.059	-0.006	-0.091
Unsupervised physical activity, min/day	0.002	0.019	-0.009	-0.086	-0.038	-0.083
Organized sports, min/day	-0.059	-0.043	-0.092	-0.005	0.028	-0.055
Organized exercise other than sports, min/day	-0.051	-0.034	-0.018	0.016	0.044	0.018
Commuting to and from school, min/day	0.009	0.023	-0.001	0.019	0.023	-0.020
Physical activity during recess, min/day	-0.093	-0.073	-0.092	-0.082	-0.051	-0.081
Sedentary behavior assessed objectively						
Awake-time sedentary behavior, min/day	0.059	-0.004	0.042	**0.151** **	0.041	**0.113** *
Sedentary behavior assessed by questionnaire						
Total sedentary behavior, min/day	0.018	0.015	0.026	**0.103** *	0.076	**0.093** *
Screen-based sedentary behavior, min/day	0.012	0.010	0.010	0.060	0.039	0.034
Sedentary behavior related to academic skills, min/day	0.041	0.034	0.046	0.022	0.007	0.027
Sedentary behavior related to music, min/day	-0.049	-0.037	-0.044	0.041	0.048	0.037
Sedentary behavior related to arts, crafts, and games, min/day	0.026	0.012	0.027	0.088	0.070	**0.094** *
Sitting and lying for a rest, min/day	0.002	0.014	0.030	0.071	0.050	0.075

Data are standardized regression coefficients from linear regression models adjusted for sex and age (Model 1) and additionally for body fat percentage (Model 2) or lean body mass (Model 3). DHEAS = dehydroepiandrosterone sulfate, IGF-1 = insulin-like growth factor-1.* $P < 0.05$, ** $P < 0.01$. Associations with $P < 0.05$ are bolded.