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Which Contributes More to Childhood Adiposity? High Levels of Sedentarism Versus Low Levels of Moderate-through-Vigorous Physical Activity: The Iowa Bone Development Study

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Abstract

Objective—To examine the relative importance of sedentarism and modeate-to-vigorous physical activity for adiposity development in children and adolescents.

Study design—277 boys and 277 girls (95% white; two-thirds of parents with college graduation or higher education) from the Iowa Bone Development Cohort Study completed body fat and accelerometry measurement at examinations of ages 8, 11, 13 and/or 15 years (during 2000 to 2009). The main exposure was accelerometry-measured sedentary time, frequency of breaks in sedentary time, and moderate-to vigorous-intensity physical activity time. The outcome was dual energy x-ray absorptiometry (DXA)-measured body fat mass

Results—Adjusted for age, height, physical maturity, and sedentary time, growth models showed that high moderate-to-vigorous physical activity time was associated with low body fat mass in both boys (coefficient $\beta = -0.10 \pm 0.02$) and girls ($\beta = -0.05 \pm 0.01$; $Ps < 0.01$). However, sedentary time and frequency of breaks in sedentary time were not associated with body fat mass.

Conclusions—This study does not support an independent effect of sedentarism on adiposity. The preventive effect of moderate-to vigorous-intensity physical activity on adiposity in children and adolescents remained strong after adjusting for the effect of sedentarism.

Keywords

accelerometer; adolescent; body fatness; DXA; cohort study; obesity; sedentary behavior; breaks in sedentary time

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The childhood obesity epidemic is a significant public health problem in the United States [1]. Adequate levels of moderate-to-vigorous physical activity have been suggested to prevent obesity [2, 3]. Prolonged time spent in sedentary behaviors (sedentary time), such as TV viewing and computer use, has been examined as a risk factor for obesity, and numerous studies have suggested that sedentary time is positively associated with obesity among children and adolescents [4, 5]. The patterns by which the sedentary time is accrued, specifically the number of events in which individuals interrupt sedentary time with bouts of light-through-vigorous physical activity, are also suggested to play an important role in body fat accumulation, and additionally, cardiometabolic health [6]. For example, four recent cross-sectional studies of adults [6–9] showed that frequency of breaks during sedentary time is inversely associated with waist circumference, body mass index, and other cardiometabolic risk factors.

It is unclear that moderate-to-vigorous physical activity and sedentarism are independent behaviors in a relation to childhood obesity. Observational data indicate clustering of behavioral patterns of low participation in club sports or exercise and prolonged sedentary time in adolescents [10]. However, given educational demands and current choices for leisure and social interaction, children and adolescents can be sedentary during most of the day and still engage in 60 or more minutes of moderate-to-vigorous physical activity each day, which is the current federal physical activity guideline for youth [2]. Understanding of the independent association of sedentarism with childhood obesity is critical in determining if sedentarism should be a focus within federal and organizational recommendations to prevent childhood obesity. In this report, using state-of- the-art measures and longitudinal observational data, we examined whether sedentary time or frequency of breaks during sedentary time is associated with body fat mass after accounting for moderate-to-vigorous physical activity.

METHODS

The Iowa Bone Development Study (IBDS) is an ongoing longitudinal study of bone health during childhood, adolescence, and young adulthood. Participants are a subset of the Iowa Fluoride Study birth cohort; 1,882 families from eight Iowa hospital postpartum wards were recruited between 1993 and 1997 [11]. Initial recruitment and examination for the IBDS were conducted between 1998 and 2002 at approximately 5 years of child age. The IBDS used rolling admission to allow Fluoride Study members to participate in any follow-up examinations. A total of 597 members of the Iowa Fluoride study cohort have participated in at least one IBDS examination. Approximately 95% of the IBDS participants are white and two-thirds of parents have college graduation or higher education. Further information about the study design and demographic characteristics of participants is available in previous publications [12, 13]. The current analysis focused on data collected from 2000 to 2009 at ages 8, 11, 13, and 15 years. The study was approved by the University of Iowa Institutional Review Board (Human Subjects). Written informed consent was provided by the parents of the children. Assent was obtained from the children.

At age 8 years, whole body scans were conducted using a Hologic QDR 2000 DXA (Hologic, Waltham, MA) with software version 7.20B in the fan-beam mode. Age 11, 13 and 15 examinations were conducted using the Hologic QDR 4500A DXA (Delphi upgrade) with software version 12.3 in the fan-beam mode. Quality control scans were performed daily using the Hologic phantom. To adjust for the difference between the two DXA machines, translational equations from 2000 DXA measures to 4500A DXA measures for age 11 records were used [13, 14]. Total body fat mass (kg) was derived from the DXA scan images.

At each study visit, children and their parents were given instructions on accelerometer wear. Actigraph uniaxial accelerometers (model 7164, Pensacola, FL; GT1M for the age 15 examination only) were mailed to participants during the autumn season (September to November). The detailed procedure for accelerometer data collection is described in previous publications [12, 13]. Participants were asked to wear the monitor during all waking hours for four consecutive days, including one weekend day, at age 8, and for five consecutive days, including both weekend days, at the other examination ages. At age 15, a substantial proportion of participants wore the monitor for less than four days. Therefore, those participants were asked to re-wear the monitor for another five days and the data collection period was extended until mid-December. Accelerometry movement counts were collected in a one-minute epoch at ages 8, 11, and 13. Accelerometry data at age 15 were collected in a five-second epoch and re-integrated to one minute.

For the accelerometry data reduction process, accelerometers were considered as having not been worn if a period of 60 consecutive minutes of zero accelerometry counts with allowance for two non-zero interruptions was encountered in the accelerometry data array. Accelerometry data were only used from participants who wore an accelerometer for a minimum of 10 hours per day and three days at each examination. Moderate-to-vigorous physical activity was defined as 2,296 or greater accelerometry counts per minute [15, 16]. Moderate-to-vigorous physical activity time (minutes/day) was the number of minutes spent in MVPA. Moderate-to-vigorous physical activity counts (counts/day) were calculated as the sum of accelerometry counts derived during moderate-to-vigorous physical activity. Extremely high counts (> 10,000 counts/min) were treated as 10,000. Time in accelerometry counts < 100 counts per minute was used to define sedentary time [15, 16]. Sedentary time was considered to be interrupted or broken if accelerometry counts were ≥ 100 counts per minute [6]. The number of interruptions was counted as frequency of breaks during sedentary time (times/day).

At each study visit, research nurses trained in anthropometry measured the child's height in centimeters (Harpenden stadiometer) and weight in kilograms (Health O Meter scale). Sitting height was measured only one time for each participant at ages ≥ 11 years to calculate the year from peak height velocity using predictive equations established by Mirwald et al [17]. Based on estimated age at peak height velocity, physical maturity status at each examination was dichotomized as pre-peak height velocity or at/post-peak height velocity.

Statistical Analyses

Statistical analyses were conducted using SAS version 9.3 (Cary, NC). Descriptive analyses were conducted by sex and examination time point. Moderate-to-vigorous physical activity time and total body fat mass were not normally distributed and therefore their natural log-transformed values were created to be used in bivariate analysis and modeling. Partial Pearson correlation coefficients were estimated between moderate-to-vigorous physical activity and sedentary indicators and body fat mass, controlling for height.

Because of the high correlation between sedentary time and frequency of breaks during sedentary time, we selected to use sedentary time as an indicator of sedentarism in multivariable models for this report. We built a growth model to examine the association between sedentary time (hours/day; continuous) and log-transformed moderate-to-vigorous physical activity time (minutes/day; continuous) and log-transformed body fat mass (kg; continuous). Moderate-to-vigorous physical activity time and sedentary time effects on body fat mass were adjusted for age (year; continuous), body size, and physical maturity. We used height (cm; continuous) as a body size indicator and peak height velocity (at/post vs. pre) as a physical maturity indicator. Lean body mass was not selected as a covariate due to its high correlation with age and height. Within-subject growth effects were also considered. The criterion by Akaike et al was compared with select a proper covariance matrix of the model; an unstructured covariance matrix was selected. To be sure that accelerometer wear time did not bias the results, additional analyses were conducted using different indicators of moderate-to-vigorous physical activity (proportion of moderate-to-vigorous physical activity time in total wear time: moderate-to-vigorous physical activity time in hours divided by wear time in hours) and sedentary time (proportion of sedentary time: sedentary time in hours divided by wear time in hours). We also repeated our analyses using log-transformed percentage body fat (body fat mass divided by total body mass × 100; continuous) as our adiposity outcome. Another set of multilevel models was built using moderate-to-vigorous physical activity counts as a moderate-to-vigorous physical activity level indicator. Finally, to test the hypothesis that sedentarism has an impact on fat mass only when moderate-to-vigorous physical activity level is low, we examined the association between sedentarism and body fat within the lowest moderate-to-vigorous physical activity tertile.

RESULTS

A total of 277 boys and 277 girls had valid data for body fat mass and accelerometry measures at one or more examinations. The time interval between accelerometer measurement and DXA scanning was three months for a half of examinations and one year for 95% of examinations. The time interval was not a significant predictor of fat mass, nor did it affect the strength of the association between moderate-to-vigorous physical activity and fat mass. Table I presents the characteristics of those participants stratified by sex and examination. Although body fat mass tended to increase over the 6.5-year follow-up among girls, body fat mass was stabilized at 13 years of age among boys. The differences in mean monitor wear time were within 30 minutes across all examination years. In both boys and girls, sedentary time increased and the frequency of breaks in sedentary time decreased at each examination ($P < 0.01$). Among boys, moderate-to-vigorous physical activity time and counts were similar at ages 8 and 11, but decreased afterwards. Moderate-to-vigorous physical activity time and counts decreased over time among girls. The mean age at peak height velocity was estimated 13.6 years for boys and 11.8 years for girls.

The correlation coefficients between moderate-to-vigorous physical activity time and sedentary time ranged from −0.26 to −0.47 among boys, and from −0.26 to −0.44 among girls (*Ps* < 0.01). The correlation coefficients between moderate-to-vigorous physical activity time and frequency of breaks during sedentary time were 0.40 to 0.51 for boys and 0.38 to 0.49 for girls (*Ps* < 0.01). Sedentary time and frequency of breaks during sedentary time were highly negatively correlated ($r \geq -0.55$ to −0.85 for both sexes; *Ps* < 0.01).

There was a trend of increasing body fat mass with higher moderate-to-vigorous physical activity time (*P*s < 0.01; Table II). After controlling for height, moderate-to-vigorous physical activity time was significantly correlated with body fat mass at each age, except for girls at age 15 (Table III). Sedentary time and frequency of breaks during sedentary time were not significantly correlated with body fat, except for boys at ages 8 and 11.

Growth models showed that a doubled moderate-to-vigorous physical activity time (e.g., 60 minutes relative to 30 minutes) was associated with approximately 3% lower fat mass among boys (β of log moderate-to-vigorous physical activity time to predict log fat mass = −0.10 ± 0.02) and approximately 1.5% lower fat mass among girls ($\beta = -0.05 \pm 0.01$; *Ps* < 0.01; Table IV). However, sedentary time was not significantly associated with adjusted body fat mass in either boys or girls. These results were consistent when using moderate-to-vigorous physical activity counts as a moderate-to-vigorous physical activity indicator (data not shown). When using frequency of breaks during sedentary time as a sedentary indicator,

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the results consistently showed no association of body fat mass with breaks during sedentary time, but a significant association with moderate-to-vigorous physical activity time ($P < 0.01$; data not shown). When the daily proportion of time spent in moderate-to-vigorous physical activity and sedentary behaviors were used as indicators of moderate-to-vigorous physical activity and sedentarism, respectively, the results were consistent with the absolute time analysis of moderate-to-vigorous physical activity and sedentary behaviors (data not shown). When percentage of body fat was used as an adiposity indicator, moderate-to-vigorous physical activity time, but not sedentary time, was associated with percentage body fat ($P < 0.01$; data not shown). Even within the lowest tertile of moderate-to-vigorous physical activity time, there was no significant association between sedentary time and body fat mass (n=197 data points for boys and 205 data points for girls; data not shown).

DISCUSSION

Our findings are consistent with previous findings of no independent association between accelerometry-measured sedentary time and waist circumference, after adjusting for moderate-to-vigorous physical activity time [3]. Although the study by Ekelund et al is cross-sectional, it had a large sample (pooled cross-sectional data from 14 studies; n=20,871 children aged 4 to 18 years). A prospective study of 403 children 7 to 9 years of age by Basterfield et al [18] reported no significant effect of accelerometry-measured sedentary time on bioelectric impedance-estimated fat mass index two years later, after adjusting for moderate-to-vigorous physical activity time. Another longitudinal study by Fulton et al [19] also examined the association between moderate-to-vigorous physical activity time, sedentary time, and adiposity among 472 adolescents 10 to 18 years of age. Moderate-to-vigorous physical activity and sedentary time were measured using a 24-hour interviewer-administered recall questionnaire. Fat mass was assessed by bioelectric impedance. The study by Fulton et al showed no association between sedentary time and different indicators of adiposity, after controlling for moderate-to-vigorous physical activity time. Another cross-sectional study by Martinez-Gomez [20] also found no association between accelerometry-measured sedentary time and cardiometabolic biomarkers after controlling for moderate-to-vigorous physical activity among 183 adolescents 13 to 17 years of age. A large-scale cross-sectional study by Mitchell et al [21] showed no association between accelerometry-measured sedentary time and DXA-derived fat mass, after controlling for moderate-to-vigorous physical activity time, among 5,434 12-year-old children. However, in a longitudinal study [22], Mitchell et al. reported a positive association between sedentary time and BMI percentile, adjusted for moderate-to-vigorous physical activity time, among 789 adolescents 9 to 15 years of age. In the Martinez-Gomez study, self-reported television viewing time was positively associated with an elevated risk of cardiometabolic biomarkers [20]. It is interesting that several publications [5, 23, 24] which have been cited as evidence of adverse effects of sedentary behaviors on obesity in children particularly focused on television viewing time. Perhaps only some sedentary behaviors, such as television viewing, are related to adiposity in youth, potentially mediated by snacking during television viewing [25], exposure to advertisement [26], sleep patterns [27], or other behavioral effects.

The 2008 Physical Activity Guidelines Advisory Committee Report [2] notes that strategies for reducing sedentary behaviors, in addition to promoting exercise, have great potential impact for public health including metabolic health. The Canadian Government has recently published a sedentary behavior guideline for children and youth, separate from physical activity guidelines [28]. These recommendations appear to eminate from adult studies which have strongly suggested the independent effects of sedentary time on metabolic health including obesity [29]. What is true for adults may not be true for children. Most adults have everyday lives that support long bouts of sitting within and outside the work place. In addition, the relative and absolute levels of activity or inactivity associated with metabolic health benefits are likely to be different between children and adults due to biological factors. Our report supports the importance of participation in moderate-to-vigorous physical activity for children to prevent obesity and questions the utility of prioritizing the reduction of sedentary time (without including a focus on increasing moderate-to-vigorous physical activity).

Several limitations of this study should be acknowledged. Due to availability issues, we changed Actigraph models at the age 15 examination. The accelerometry output may differ between the two models with greater variability expected in the 7164 model due to its analog circuit filtering system when compared with the GT1M with a digital filtering system. However, we calibrated all 7164 model accelerometers with a shaker prior to sending them to participants. Also, laboratory work by Kozey et al suggests that the difference is random, and when using cut-point methods, the results from the 7164 model and GM1 model are comparable [30]. Our cohort study experienced significant attrition at age 15. However in sub-set analyses for those who completed the age 15 examination and those who did not, the associations among sedentary time, moderate-to-vigorous physical activity and body fat mass were consistent with the current report. Our cohort is a sample of white highly educated population. Therefore, the study results should be generalized cautiously to the general population of children. We did not consider energy intake as a predictor of body fat mass. Genetic predisposition to adiposity also was not considered. Finally, this is an observational study, and therefore we cannot eliminate error introduced by residual and unmeasured confounding factors.

Our construction of growth models allowed us to minimize differences of timing and tempo in adiposity changes among children. The use of objective and accurate measures for both physical activity and adiposity improved measurement precision and increased internal validity. The results of this this study do not support an independent effect of sedentary time nor frequency of breaks in sedentary time on adiposity. There was a strong preventive effect of moderate-to-vigorous physical activity on adiposity in children and adolescents.

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LIST OF ABBREVIATIONS

IBDS	Iowa Bone Development Study

REFERENCES

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Table 1

Characteristics of participants.

	Boys				Girls			
	Age 8	Age 11	Age 13	Age 15	Age 8	Age 11	Age 13	Age 15
	n=243	n=219	n=199	n=133	n=252	n=233	n=202	n=134
	Mean (95% CI)				Mean (95% CI)			
Age (years)	8.8 (8.7, 8.9)	11.2 (11.2, 11.3)	13.3 (13.2, 13.3)	15.4 (15.3, 15.4)	8.8 (8.7, 8.8)	11.2 (11.2, 11.3)	13.2 (13.2, 13.3)	15.3 (15.3, 15.4)
Height (m)	1.35 (1.34, 1.36)	1.49 (1.48, 1.50)	1.63 (1.62, 1.64)	1.75 (1.74, 1.76)	1.33 (1.32, 1.34)	1.49 (1.48, 1.50)	1.61 (1.60, 1.62)	1.64 (1.63, 1.66)
Body weight (kg)	33.7 (32.5, 34.9)	45.4 (43.6, 47.2)	58.2 (55.9, 60.4)	69.8 (66.9, 72.7)	31.8 (30.8, 32.9)	44.6 (43.0, 46.2)	55.8 (53.8, 57.8)	61.9 (59.4, 64.4)
BMI (kg/m^2)	18.3 (17.8, 18.7)	20.2 (19.6, 20.8)	21.7 (21.0, 22.3)	22.7 (21.9, 23.6)	17.8 (17.4, 18.3)	19.8 (19.3, 20.4)	21.5 (20.8, 22.2)	22.9 (22.0, 23.7)
Accelerometer wear time (hrs/day)	12.6 (12.5, 12.7)	12.6 (12.5, 12.7)	12.7 (12.6, 12.8)	13.1 (12.9, 13.2)	12.5 (12.4, 12.6)	12.5 (12.4, 12.6)	12.9 (12.7, 13.0)	13.0 (12.8, 13.2)
Daily breaks in sedentary time (times/day)	470 (462, 479)	441 (432, 450)	391 (381, 401)	308 (298, 319)	460 (452, 468)	420 (412, 429)	368 (359, 378)	284 (273, 295)
Sedentary time (hrs/day)	4.8 (4.7, 4.9)	5.3 (5.2, 5.4)	6.4 (6.2, 6.6)	8.1 (7.9, 8.3)	4.9 (4.8, 5.0)	5.6 (5.5, 5.7)	6.9 (6.7, 7.0)	8.4 (8.2, 8.6)
MVPA time (min/day)	63.2 (59.8, 66.6)	63.6 (61.8, 69.5)	51.5 (49.3, 56.0)	40.1 (37.1, 44.3)	45.0 (42.6, 47.5)	38.1 (35.8, 40.4)	33.2 (30.6, 35.9)	28.1 (25.0, 31.2)
MVPA counts ($\times 10^3$ counts/day)	243 (227, 259)	263 (245, 281)	204 (189, 219)	153 (136, 170)	174 (162, 186)	148 (137, 159)	132 (119, 145)	105 (91, 118)
Body fat mass (kg)	8.1 (7.5, 8.8)	11.9 (10.9, 13.0)	13.8 (12.6, 15.1)	13.5 (12.0, 15.1)	8.8 (8.2, 9.4)	12.7 (11.8, 13.6)	15.3 (14.1, 16.4)	17.6 (16.0, 19.1)

BMI, body mass index; CI, confidence interval; MVPA, moderate- to vigorous-intensity physical activity.

Table 2

Body fat mass according to sedentary and MVPA levels

	Boys				Girls			
	Age 8	Age 11	Age 13	Age 15	Age 8	Age 11	Age 13	Age 15
	n=243	n=219	n=199	n=133	n=252	n=233	n=202	n=134
	Mean (95% CI)				Mean (95% CI)			
Body fat mass (kg) by sedentary time level†								
Low	7.1 (6.3, 7.9)	11.4 (9.6, 13.1)	12.8 (10.9, 14.6)	14.8 (11.7, 18.0)	8.0 (7.3, 8.8)	12.6 (10.7, 14.4)	15.8 (13.7, 17.9)	17.6 (14.8, 20.4)
Medium	7.9 (6.8, 8.9)	10.7 (9.3, 12.2)	13.8 (11.3, 16.3)	12.9 (10.3, 15.5)	9.0 (7.8, 10.2)	13.3 (11.8, 14.8)	13.9 (12.2, 15.6)	17.1 (14.4, 19.8)
High	9.4 (8.1, 10.7)	13.8 (11.8, 15.7)	14.8 (12.6, 17.1)	12.9 (10.5, 15.2)	9.3 (8.3, 10.3)	12.3 (10.8, 13.7)	16.1 (14.0, 18.2)	18.0 (15.4, 20.6)
Body fat mass (kg) by MVPA time level†								
Low	9.9 (8.5, 11.3)	13.8 (11.8, 15.8)	16.6 (13.9, 19.2)	14.7 (11.5, 17.8)	10.4 (9.1, 11.6)	14.4 (12.5, 16.3)	16.5 (14.6, 18.5)	19.2 (16.3, 22.1)
Medium	7.9 (6.9, 8.8)	12.6 (10.7, 14.5)	13.2 (11.3, 15.2)	13.3 (11.0, 15.5)	8.4 (7.6, 9.3)	12.6 (11.2, 14.1)	16.0 (13.8, 18.2)	16.9 (14.4, 19.4)
High	6.7 (5.9, 7.4)	9.4 (8.3, 10.5)	11.7 (9.9, 13.4)	12.7 (9.9, 15.4)	7.5 (6.8, 8.2)	11.1 (9.9, 12.4)	13.2 (11.6, 14.9)	16.6 (14.0, 19.3)

BMI, body mass index; CI, confidence interval; MVPA, moderate- to vigorous-intensity physical activity.

†Sedentary time and MVPA time were categorized by gender- and wave-specific tertile cut-points.

Table 3

Partial correlation coefficients of time spent in sedentary behaviors and moderate- to vigorous-intensity physical activity and body fat mass. Cross-sectional analysis.

	Boys				Girls			
	Age 8	**Age 11**	**Age 13**	**Age 15**	**Age 8**	**Age 11**	**Age 13**	**Age 15**
	n=243	**n=219**	**n=199**	**n=133**	**n=252**	**n=233**	**n=202**	**n=134**
	Log body fat mass (kg)							
Breaks in sedentary time (times/day)	−0.17**	−0.13*	−0.12	0.01	−0.05	−0.07	−0.00	−0.02
Sedentary time (hrs/day)	0.20**	0.10	0.04	−0.10	0.08	0.05	−0.01	−0.08
Log MVPA time (min/day)	−0.35**	−0.25**	−0.20**	−0.21*	−0.32**	0.17**	−0.18*	−0.13

MVPA time, time spent in moderate- to vigorous-intensity physical activity.

Pearson correlation coefficients with log-transformed body fat mass (kg) were obtained after controlling for height effect.

* $P < 0.05$;

** $P < 0.01$.

Table 4

Body fat mass prediction multivariable growth models.

	Boys (n=277)		Girls (n=277)	
	b ± s.e.	***P-value***	***b ± s.e.***	***P-value***
Intercept	0.05 ± 0.26	0.85	0.16 ± 0.18	0.38
Age (years)	0.03 ± 0.02	0.08	0.02 ±0.01	<0.05
Peak height velocity age (at/post vs. pre)	−0.33 ± 0.03	<0.01	−0.03 ± 0.02	0.19
Height (cm)	0.02 ± 0.00	<0.01	0.02 ± 0.00	<0.01
Sedentary time (hrs/day)	−0.01 ± 0.01	0.21	−0.01 ± 0.01	0.24
Log MVPA time (min/day)	−0.10 ± 0.02	<0.01	−0.05 ± 0.01	<0.01

MVPA time, time spent in moderate- to vigorous-intensity physical activity; *b*, parameter estimate; *s.e.*, standard error.

Sex-specific growth model: log body fat mass (kg) = age (years) + peak height velocity age (pre/post) + height (cm) + sedentary time (hrs/day) + log MVPA time (min/day). Growth effects within individuals were taken into account. Participants with measurement data from at least one examination were included in the analysis.