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Secular trends in body mass index in German children and adolescents: a cross-sectional data analysis via CrescNet between 1999 and 2006

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Abstract

To assess secular trends in alterations in body mass index (BMI) in German children and adolescents between 1999 and 2006, we performed an analysis using data from a computerized database (CrescNet) and focusing on the data ranges above the 97th percentile (P97) and below the median (P50). This cross-sectional assessment of BMI data used a total of 143 495 single values (73 290 males and 70 205 females aged 0.5-17.5 years) from screening and/or consulting visits at 1 of the 294 participating German pediatricians. Body mass index data were calculated from standardized measurements of body weight and height entered into the CrescNet database. Individual percentiles were estimated according to German reference data sets. Across all age groups, the respective mean value of children with BMI above P97 increased from 5.32% to 7.02% in boys and from 5.70% to 7.18% in girls between 1999 and 2006, whereas those below P50 decreased from 48.52% to 43.71% in boys and from 47.48% to 42.57% in girls. The proportions of obese children (above the 97th percentile) were significantly higher than estimated by German reference values throughout the study period. The significant increase in childhood obesity between 1999 and 2006 was more pronounced in boys compared to girls. In conclusion, the cross-sectional study performed at a large cohort of German children and adolescents reveals an alarming increase in the number of obese children and adolescents and an accompanied shift toward higher BMI values. As the number of children below the 50th centile decreases accordingly, the shift in the distribution panel of the German reference percentile curves affecting the whole population can be observed.

1. Introduction

It is well recognized that the prevalence of obesity has increased dramatically over the past decades in children and adolescents. This increase is considered to have reached an epidemic scale on the international level [1-3]. In addition, comorbidities related to overweight and obesity, such as type 2 diabetes mellitus and cardiovascular disease, are increasing [3].

An asymmetric shift has been reported in the distribution of body mass index (BMI) as the morbidly obese children being at greatest risk to develop associated comorbidities become even more obese [4]. The extent to which obesity is affecting children in Germany and the rate at which the prevalence of obesity increases have been investigated in several studies [5-7]. In view of the enormous potential health-economic impact of pediatric obesity, its comorbidities and consequential diseases in childhood and adulthood at present and in the future [8-13,18], programs for the prevention and treatment of overweight and obesity are of paramount importance. However, such programs need to be based on reliable, representative, and recent data [14-17] that are collected in an ongoing process, and their success or failure needs to be assessed in a timely manner and reassessed at regular intervals. Established at the Leipzig University Hospital for Children and Adolescents (Leipzig, Germany) in 1998, CrescNet (www.crescnet.org) is a computer-based, auxologic collaborative network connecting pediatricians in

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practice with endocrine specialists. Originally a regional project, CrescNet is in the process of expanding geographically to become a national database, one of its main objectives being to collect, in a standardized manner, large volumes of body length/height and weight data for timely analysis [9,18,19]. A special feature of CrescNet is that it longitudinally records data for children and adolescents who present for routine medical checkups. For this analysis, we excluded all children with known chronic diseases and data from endocrinologic specialists, to avoid selection bias.

We have compared our data with the generally accepted reference values published by Kromeyer-Hauschild et al [20] in 2001, based on data from 17 relevant studies conducted in various regions of Germany between 1985 and 1999. A major focus of our work has been to address the question whether and, if so, to what extent the proportion of obese children and adolescents has been increasing in Germany during the investigated period. The cross-sectional study presented herein has analyzed CrescNet data between 1999 and 2006 using statistical techniques and visualization methods, including kernel density estimation and contour plots, for timely identification and assessment of secular BMI trends in our study population.

2. Subjects and methods

Standardized body weight and height determinations were obtained from CrescNet, a collaborative network of pediatricians and centers for pediatric endocrinology connected via a central database system. All German pediatricians are invited to join the CrescNet network. For historical reasons, however, the participation in Saxony is higher than in other federal states. The body weight and height data were collected during routine screening examinations and other pediatric consultations in 1999 and 2006. All data were entered anonymously into the central database, which is based on the PostgreSQL database management system, version 7.4. The present cross-sectional analysis was based on a randomly selected single measurement per child from either 1999 or 2006. Children with known chronic diseases or data not directly obtained by the pediatricians were excluded from the analysis. No formal study protocol, ethics committee approval, or written informed consent was required for the study, but parents and guardians had the right, in accordance with the German data protection law, to refuse use of their children's data.

As of June 30, 2007, the cut-off point for the present analysis, the database contained data for 34 062 children measured in 1999 (17 355 boys and 16 707 girls) and 109 433 children measured in 2006 (55 935 boys and 53 498 girls), aged 0.5-17.5 years. Subjects were assigned to age groups, defined as 1 (0.5-1.5), 2 (1.5-2.5), and so on, up to 17 (16.5-17.5) years. The raw data of children analyzed per age group are presented in Table 1.

Table 1
Study population according to age group

Age	Male		Female	
	1999	2006	1999	2006
1	2245	8955	2065	8737
2	1647	6983	1516	6715
3	923	3451	937	3410
4	1261	6485	1103	6309
5	1046	6355	976	5971
6	751	3524	728	3296
7	761	2981	695	2867
8	858	2652	854	2511
9	1163	2385	1117	2330
10	1248	2103	1172	2018
11	1232	1867	1233	1672
12	1165	1648	1121	1538
13	972	1627	946	1475
14	768	1440	845	1201
15	628	1177	639	1074
16	424	1314	468	1307
17	263	988	292	1067

All measurements were performed by trained staff according to standardized procedures. Body weight was measured using medically calibrated scales, with subjects wearing only light underwear. The standardized methods used to measure body length (infants up to 2 years of age), height (children older than 2 years and adolescents), and weight have been described elsewhere in detail [9,18,19]. All 294 participating pediatricians were supplied with, and used, the same type of stadiometer [21-23].

The data were collected using purpose-designed bar-coded data tickets and submitted to the study coordination center at the Department of Auxology at the Hospital for Children and Adolescents, University of Leipzig, for entry into the database and further processing. Data selection bias was avoided by collecting data for all children presenting to the participating pediatricians, that is, for routine checkups, screening examinations or treatment purposes, and selecting randomly only one measurement per child.

2.1. Statistics

Body mass index values (kg/m^2) were calculated by dividing body weight in kilograms by the square of height in meters (infants) or height (all others) measured in meters. Empirical percentiles were calculated from the individual BMI data. The individual BMI data were also converted to z scores according to German national reference data — BMI percentiles from German children — as recommended by the "Arbeitsgemeinschaft Adipositas im Kindes- und Jugendalter" [20]. These BMI reference values were derived using Cole's LMS method [24-26], which allows for the calculation of SDS values (z scores) even in the case that characteristics do not fit a normal distribution curve, such as the BMI.

Data analysis was performed using "R," a language and environment for statistical computing and graphics, version 2.4 [27].

Statistical methods included descriptive statistics and 2 nonparametric tests, the χ^2 test and the Kolmogorov-Smirnov test. Descriptive statistics were used to investigate the occurrence of mean changes across male and female age groups in the percentage of children with a BMI above the 97th percentile (P97-Kromeyer-Hauschild data [KH]), or below the 50th percentile (P50-KH), of the German reference curves in 1999 and 2006. The χ^2 test was used to ascertain the statistical significance of differences, by sex and age group, found over the study period in the percentages of children in CrescNet with a BMI above P97-KH or below P50-KH. Similarly, it was also used to test whether the differences between the 2006 and 1999 CrescNet data were statistically significant. The Kolmogorov-Smirnov test was used to test whether the BMI distributions of the 2006 and 1999 CrescNet BMI data differed in a statistically significant manner.

Graphical methods were used for data visualization. The male and female BMI values at P97 and P50 observed in 1999 and 2006 were plotted against age groups 1 to 17 years. To obtain overall visual representations of the changes in the distributions, we constructed density difference plots using a method similar to that described by Bellhouse and Stafford [28]; such plots compare BMI values between 2006 and 1999 at a certain age, addressing the question whether a given BMI value was more present in 2006 than in 1999. The density functions for boys and girls were first determined by 2-dimensional kernel density estimation using the "bkde2D" function of R, with a normal distribution with a bandwidth of 0.5 years and 0.5 BMI points being used as the kernel. Then, contour plots of the difference between the 2006 and 1999 BMI density functions were calculated using the filled-contour function to visualize the BMI shifts taking place during the study period.

3. Results

The number of subjects analyzed per age group and year are presented in Table 1. The BMI values observed at the 97th percentile (P97) and 50th percentile (P50, or median), respectively, according to age group and year are summarized in Tables 2 and 3 as well as in Figs. 1 and 2. A significant increase in BMI values for both P97 and P50 can be observed within the study period. Although the deviation in P50 seems smaller, it includes a larger number of subjects, leading to an even more significant discrepancy compared to P97, as explained below.

Comparison of our 2006 and 1999 data using the Kolmogorov-Smirnov test showed that differences in the distribution of BMI values were statistically significant ($P < .05$) in the age groups 4 to 5 and 9 to 17 years in boys and in the age groups 2 to 4, 6 to 7, 13, and 15 to 17 years in girls, and not significant in the other age groups.

Figs. 3 and 4 illustrate the contour plots obtained for boys and girls, respectively, by subtracting the respective density functions for 1999 from those for 2006. The upward trends in BMI at various ages are represented by vertical shifts from darker to lighter shades of gray. In boys, shifts toward a higher BMI are fairly evenly distributed across the age spectrum, with the exception of children of 7 to 8 years, where no trend is apparent. In girls, the changes are very strong at the center of the distribution (light gray regions marking higher densities are more localized compared to boys) and the range with no apparent trend covers ages 7 to 12 years. In both cases, we see wide areas at the lower part of the distribution with lower densities in 2006 than in 1999 (shown as dark gray) as a central feature of the plots.

Table 2
Empirical P97 of the BMI (kg/m^2) of boys and girls participating in the CrescNet survey by age group in 1999 and 2006

Age	Male			Female		
	P97 BMI		Increase (%)	P97 BMI		Increase (%)
	1999	2006		1999	2006	
1	20.1	20.0	−0.35	19.7	19.7	−0.01
2	19.4	19.3	−0.41	19.0	19.1	0.68
3	18.6	18.7	0.09	18.4	19.0	3.44
4	18.4	18.8	2.21	18.5	19.0	2.44
5	18.9	19.4	2.79	20.4	19.8	−3.25
6	19.9	20.9	5.17	20.6	21.1	2.32
7	21.5	22.8	6.04	22.6	22.7	0.75
8	23.6	23.8	1.00	23.1	23.1	0.33
9	24.3	25.2	4.09	24.5	24.7	0.71
10	25.2	26.2	4.14	25.4	25.5	0.02
11	26.8	27.6	3.03	26.8	26.9	0.66
12	27.0	29.1	7.65	28.2	28.7	1.58
13	28.2	29.4	4.25	29.0	30.1	3.86
14	29.1	29.9	2.75	29.9	30.5	2.11
15	30.5	31.4	2.77	29.0	32.3	11.16
16	29.8	32.8	10.01	30.9	33.6	8.64
17	30.6	32.3	5.68	32.0	32.6	1.92

When comparing our data with the KH reference curves for Germany [20], considerable discrepancies can be found. The mean percentage of boys with a BMI above P97-KH increased by 1.8 percentage points from 5.2% in 1999 to 7.0% in 2006. Similarly, the mean percentage of girls with a BMI above P97-KH increased by 1.5 percentage points from 5.7% in 1999 to 7.2% in 2006. In contrast, the mean percentage of boys with a BMI below P50-KH decreased by 4.8 percentage points from 48.5% in 1999 to 43.7% in 2006. Similarly, the mean percentage of girls with a BMI below P50-KH decreased by 4.9 percentage points from 47.5% in 1999 to 42.6% in 2006. The calculated differences for boys and girls with a BMI lower than P50-KH as well as the χ^2 tests for the proportion of children with a BMI above P97-KH in 2006 vs 1999 were statistically significant ($P < .05$) in most analyzed age groups (see Table 4). We conclude that, although the empirical P50 shows a less pronounced alteration compared to German reference centiles than P97 when comparing our data from 2006 with 1999, the changes at the center of the distribution are more dramatic, and more significant, than that in the upper fringe. This is in agreement

Table 3
Empirical P50 (or median) of the BMI (kg/m^2) of boys and girls participating in the CrescNet survey by age group in 1999 and 2006

Age	Male			Female		
	P50 BMI		Increase (%)	P50 BMI		Increase (%)
	1999	2006		1999	2006	
1	17.0	17.0	−0.12	16.6	16.5	−0.24
2	16.3	16.3	−0.12	15.9	16.1	0.91
3	15.7	15.8	0.51	15.5	15.7	1.23
4	15.5	15.6	0.97	15.3	15.5	0.72
5	15.4	15.5	0.52	15.3	15.4	0.52
6	15.4	15.6	1.01	15.3	15.6	1.96
7	15.8	15.8	0.32	15.7	15.8	0.96
8	16.2	16.2	0.34	16.2	16.3	0.74
9	16.6	16.7	0.79	16.6	16.9	1.80
10	16.9	17.4	2.81	17.3	17.4	0.52
11	17.7	18.0	1.81	17.9	18.2	1.96
12	18.2	18.8	3.30	18.5	18.9	2.14
13	18.8	19.2	1.91	19.2	19.9	3.75
14	19.3	20.1	3.93	20.1	20.4	1.64
15	19.7	20.6	4.54	20.5	21.2	3.66
16	20.1	21.1	4.64	20.9	21.7	3.59
17	20.7	21.6	4.23	21.0	21.8	3.57

with the contour plots, where these shifts at the center of the distribution can be clearly seen.

4. Discussion

Statistical analysis of our data revealed a significantly increased proportion of children and adolescents above the 97th centile and a decreased proportion below the 50th BMI percentile in most age groups in our study population between 1999 and 2006, compared with the German reference values that were obtained between 1985 and 1999.

In addition, when comparing our own data for 2006 vs 1999, we found an increasing shift toward higher BMI values, which has attained statistical significance for the most age groups. This upward secular trend continued even within our study period, with obese boys (statistically significant differences in 9 of 17 age groups) being more affected than obese girls (statistically significant differences in 5 of 17 age groups). At this point, however, it must remain an open question whether this sex difference is due to a shift in the BMI of obese girls that may already have taken place in the 1990s or whether BMI developments have generally been more stable in obese girls, and they are currently in the process of "catching up." The shift around the 50th percentile, however, is highly significant across all groups older than 9 years in boys and older than 12 years in girls and more affected in girls in the younger age groups.

Taken together, these results strongly suggest an upward secular trend or shift, even within the study period (1999-2006), suggesting an increase in the BMI of children and

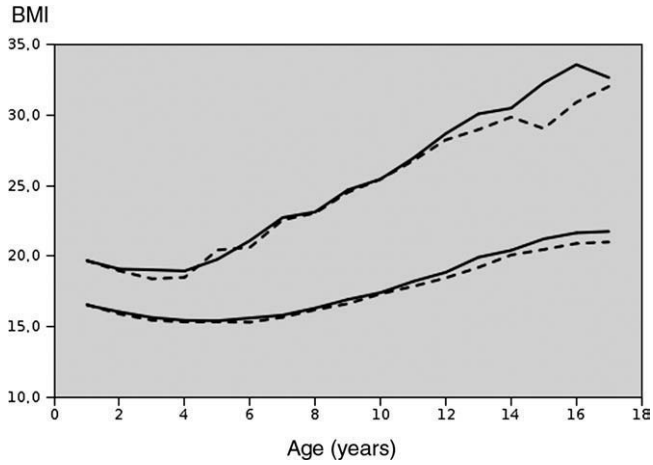

Fig. 2. The empirical 50th and 97th percentile curves for the BMI of girls participating in the CrescNet survey 1999 (dotted line) and 2006 (solid line).

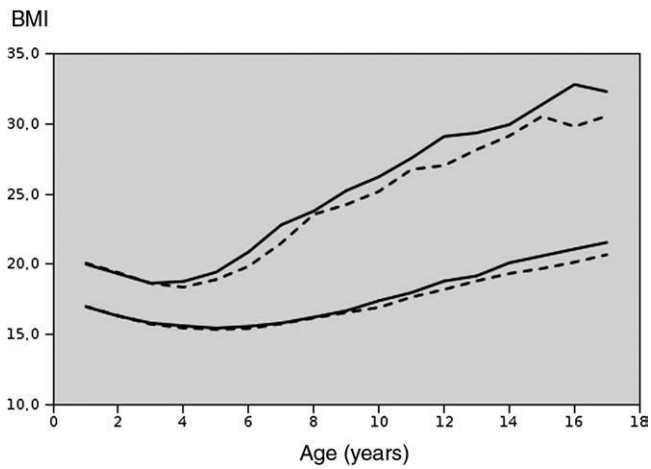

Fig. 1. The empirical 50th and 97th percentile curves for the BMI of boys participating in the CrescNet survey 1999 (dotted line) and 2006 (solid line).

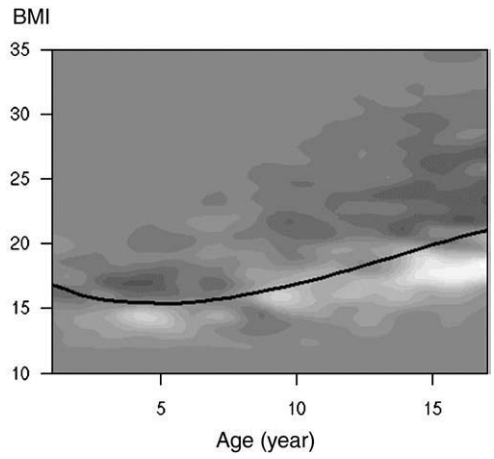

Fig. 3. Differences in BMI density functions for boys participating in the CrescNet survey between 1999 and 2006. Mid-gray tone indicates no change, and the darker and lighter shades of gray represent higher and lower densities, respectively. The solid black line marks P50-KH.

adolescents across the entire population. In most studies, only the prevalence rates of overweight and obesity were calculated, and they do not focus on changes over time in the distribution of BMI.

With regard to graphical methods of BMI data analyses, we have found contour plots to be useful for qualitative visualization of differences between density functions. They convey an overall impression of the changes taking place between 2 points in time and allow visual comparison of corresponding data sets, for example, for boys and girls. For instance, comparison of Figs. 3 and 4 indicates that the upward trend in BMI is greater and more evenly spread across age groups in boys, whereas in girls the trend is less distinct in the intermediate age groups from approximately 7 to 12 years. However, although useful as supplementary tools, the graphical methods cannot replace the statistical tests, which are less amenable to intuitive understanding.

Overall, in our experience to date, CrescNet provides an established database for timely data analysis and identification of secular trends in BMI, offering a basis for the design and implementation of countermeasures in the form of, for example, prevention programs. One advantage of the CrescNet data is that they have no selection bias for overweight/obesity because length/height and weight data are collected for all children seen by the participating pediatricians, regardless of the reasons for the visit.

Our finding that the proportion of obese children and adolescents is markedly increasing in Germany in conjunction with a general secular trend toward higher BMI in age groups 1 to 17 years has clear implications for preventive programs targeting children, parents, health professionals, and others working with children. In the light of recent health-economic studies in the United States, the adverse consequences of childhood obesity are likely also to impose ever-increasing burdens on the health care systems in Germany and other European countries [9,12,18]. It is therefore crucial to place emphasis on prevention, rather than crisis management, to avoid public health crises in the decades to come. This will require the collection, and rapid analysis, of large bodies of relevant data, such as the CrescNet database, on a national and international scale to identify in a timely manner any changes in the proportion of overweight and obese children and adolescents as well as secular BMI trends, to develop and implement programs for obesity prevention and treatment and to assess their effectiveness at regular intervals.

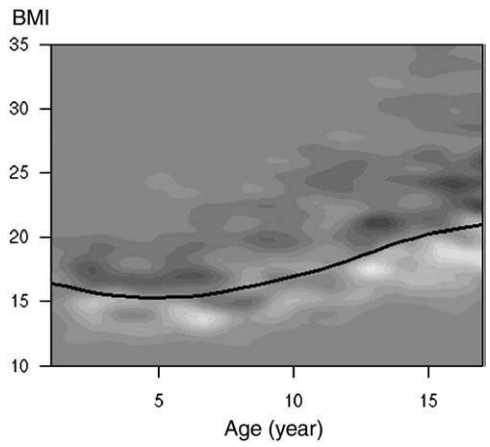

Fig. 4. Differences in BMI density functions for girls participating in the CrescNet survey between 1999 and 2006. Mid-gray tone indicates no change, and the darker and lighter shades of gray represent higher and lower densities, respectively. The solid black line marks P50-KH.

Table 4
Significance of the difference between 1999 and 2006

Age	Chi-square-test p-values			
	BMI > P97 KH 1999 vs 2006		BMI < P50 KH 1999 vs 2006	
	Male	Female	Male	Female
1	0.255	0.658	0.221	0.244
2	0.799	0.259	0.357	0.008
3	0.622	0.026	0.736	0.009
4	0.017	0.180	0.002	0.006
5	0.251	0.405	0.065	0.154
6	0.010	0.136	0.064	0.001
7	0.431	0.272	0.384	0.311
8	0.682	0.259	0.496	0.169
9	0.003	0.546	0.298	0.013
10	0.001	0.283	0.001	0.371
11	0.071	0.026	0.031	0.019
12	0.001	0.527	0.001	0.093
13	0.038	0.397	0.021	0.000
14	0.038	0.483	0.000	0.020
15	0.019	0.003	0.000	0.002
16	0.034	0.041	0.000	0.000
17	0.188	0.038	0.001	0.001

Result of the χ^2 test (P value) of the proportions of children above P97-KH and below P50-KH. Gray background indicates significant differences.

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