



Epidemic obesity: are genetic factors involved via increased rates of assortative mating?

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OBJECTIVE: Prevalence rates of obesity have been increasing in several countries over the past two decades. Mainly secular changes in energy intake and expenditure have been invoked to underlie the increasing rates; genetic factors have not been considered because of the very recency of this phenomenon. We hypothesize that genetic factors might very well be involved via an increased rate of assortative mating between obese individuals. We speculate that the recent upsurge in social stigmatization of obese individuals underlies the hypothesized increase in assortative mating. **DESIGN:** To accumulate evidence for our hypothesis we analysed deduced rates of assortative mating among parents of extremely obese children and adolescents, who belonged to two different large study groups ($n = 201$ and $n = 270$). For this purpose we calculated parental body mass indices (BMIs) based on (a) measured current heights and weights, (b) self-reported current heights and weights, and finally (c) measured current heights and recalled weights at ages 20 and 30, respectively. BMI centiles were determined which in turn were attributed to the respective BMI decile. Deduced rates of assortative mating were evaluated in bivariate histograms of the paternal and maternal BMI deciles. **RESULTS:** High rates of assortative mating were observed as deduced from the bivariate histograms, which revealed a fairly consistent pattern. Thus, in the first study group almost 35% of the parental pairs had a BMI in the tenth decile; over 50% of the mothers and fathers had a BMI in this top decile. Recalled parental BMIs at ages 20 and 30 also clustered in the upper decile. These results were basically replicated in the second study group. In addition, parental loading on the tenth decile was shown to be higher for the subgroup of children and adolescents who had a BMI equal to or exceeding the highest BMI of the population-based age and gender matched control group. **CONCLUSIONS:** Our results indicate that assortative mating is common among parents of extremely obese children and adolescents, ascertained between 1995 and 1997. In addition, the parental loading on the tenth decile is most prominent for the most obese children. Whereas we are unable to document an increased rate of assortative mating, we interpret our results as being consistent with the hypothesis that an increased rate of assortative mating has contributed to the recent rise in obesity rates in several countries. Thus, assortative mating warrants further studies to assess its impact on obesity prevalence rates through both genetic and non-genetic mechanisms. Our results suggest that assortative mating might especially increase the rates for extreme obesity.

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Introduction

The recent rise in the prevalence of obesity is an issue of major concern for the health systems of several countries. In the USA the increase in the prevalence of all classes of obesity has been dated to the time period between the National Health and Nutrition Examination Surveys (NHANES) II and III which were conducted from 1976 to 1980 and from 1988 to 1994, respectively. Between these two surveys the prevalence of obesity increased by more than one-half rising from 14.5% to 22.5%. Similar trends have been observed in other countries in Europe, North and South America.¹

Children and adolescents have not been exempt from this trend. Quite the contrary, the increase in obesity in children in the USA has been substantial. Thus, between the National Health Examination Survey (NHES, cycles II and III; 1963–1965 and 1966–1970) and NHANES III (1988–1991) overweight defined by the NHES 85th percentile of BMI increased by approximately 7% for 6–11 y olds and for 12–17 y olds. When overweight was defined by the NHES 95th percentile of BMI the increase was approximately 5% for 6–11 y olds and 6% for 12–17 y olds. These increments translate into relative increases of 40% using the 85th centile as a cutoff and 100% upon use of the 95th centile.² In a cross-sectional study of German children and adolescents treated as inpatients for extreme obesity between 1985 and 1995 we reported a significant increase of the mean BMI of almost 2 kg/m² over this 10 y period.³ Within this extreme group the increments were most pronounced in the uppermost BMI ranges. Thus, in males the absolute BMIs corresponding to the tenth decile of the study group rose from 32.7 kg/m² in 1985 to almost 38 kg/m² in 1995.

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Table 1 Absolute body mass index values (kg/m²) corresponding to the 90th centile in the German population as assessed with the German National Nutrition Survey¹¹

Age range (y)	10–12	13–14	15–16	17–18	19–20	21–25	26–30	31–35	36–40	41–45	46–50	51–55	56–60
Males													
90th centile	22.5	23.1	24.5	24.7	25.9	26.2	27.7	27.8	29.7	29.5	29.4	30.1	30.5
Females													
90th centile	22.1	23.6	23.9	24.1	24.2	25.3	26.4	27.4	28.7	28.3	29.7	30.8	30.4

Table 2 Descriptive anthropometric data of index patients of study group 1 and their parents

Index patients (n = 201)	Mean	Standard deviation	Minimum	Maximum
Age (y)	13.56	2.35	7.00	19.50
BMI (kg/m ²)	32.09	4.97	22.68	49.74
BMI centile	99.35	1.33	92.00	100.00
Mothers				
<i>Current data:</i>				
Age	41.20	5.70	27.49	62.03
BMI	30.97	7.04	17.15	55.47
BMI centile	83.55	22.09	0.00	100.00
<i>Recalled BMI at age 20:</i>				
BMI	23.75	4.95	14.30	47.03
BMI centile	66.70	33.61	0.00	100.00
<i>Recalled BMI at age 30:</i>				
BMI	27.32	6.06	16.46	47.03
BMI centile	76.33	26.34	0.00	100.00
Fathers				
<i>Current data:</i>				
Age	44.70	6.37	30.55	63.21
BMI	30.80	5.72	20.94	54.33
BMI centile	80.43	25.29	2.00	100.00
<i>Recalled BMI at age 20:</i>				
BMI	24.82	4.26	16.56	44.98
BMI centile	64.81	30.71	0.00	100.00
<i>Recalled BMI at age 30:</i>				
BMI	27.67	6.06	19.88	44.98
BMI centile	73.23	26.34	5.00	100.00

The mechanisms underlying this increase in the prevalence of obesity are unknown. Environmental factors have commonly been invoked as the underlying cause. Basically, both an increased energy intake and a reduced level of physical activity have been discussed.¹ In England the increase in obesity rates has been attributed to the latter mechanism. Thus, in this country the average energy intake even decreased somewhat within the last two decades, whereas indirect evidence stemming from the increases in hours spent watching television and from the average number of cars per household points to reduced levels of physical activity as the relevant causative factor.⁴ However, all in all a methodologically sound delineation of environmental factors leading to increased rates of obesity has not been achieved.

Genetic factors have previously not been considered as a contributing cause. On the contrary, the fact that the increased rates of obesity have been observed within the last two decades has been viewed as evidence that genetic factors cannot be held responsible. Indeed, systematic changes of the population-based frequencies of specific alleles predisposing to

Table 3 Descriptive anthropometric data of index patients and their parents of study group 2a (Figure 4) and 2b (Figure 5). The index patients all had a BMI equal to or above the maximal BMI observed in population based controls matched for age and gender (11)

	Mean	Standard deviation	Minimum	Maximum
Study group 2a				
<i>Index patients (n = 142):</i>				
Age	13.33	2.36	9.00	20.00
BMI	33.45	4.51	26.56	50.47
BMI centile	100.00	0.00	100.00	100.00
Mothers:				
Age	40.09	5.57	30.00	55.00
BMI	28.53	5.97	17.26	44.99
BMI centile	77.54	24.57	0.00	100.00
Fathers:				
Age	43.66	6.64	31.00	65.00
BMI	29.28	4.30	19.27	45.13
BMI centile	76.56	27.20	1.00	100.00
Study group 2b				
<i>Index patients (n = 128):</i>				
Age	12.70	2.31	7.00	17.00
BMI	27.03	3.01	19.52	34.60
BMI centile	97.28	2.23	90.00	99.00
Mothers:				
Current age	38.80	4.99	29.00	53.00
BMI	25.93	5.48	17.01	45.00
BMI centile	64.75	29.86	0.00	100.00
Fathers:				
Current age	42.10	6.22	31.00	69.00
BMI	27.65	4.23	19.76	48.42
BMI centile	67.76	27.61	3.00	100.00

obesity cannot possibly have occurred within this short time span. However, in the following we propose that an increase in the rate of assortative mating could very well constitute a genetic contribution to the observed phenomenon. Our hypothesis is based on evidence suggesting that stigmatization of obese individuals represents a rather recent social phenomenon, thus invariably leading to increased rates of assortative mating. As a consequence, the offspring have a higher loading with both additive and non-additive genetic factors underlying obesity.

To test this hypothesis reliably would have required continuous family data collected over the past 50 y within a well-defined segment of the population. Because we do not have epidemiological data of this type we looked at deduced rates of assortative mating among the parents of extremely obese German children and adolescents contacted between 1995 and 1997. We hypothesized that in a substantial proportion of families both parents are obese. Based on our hypothesis we expected that the respective parents

were already both obese when they originally met. Finally, we expected to observe the highest rate of assortative mating among the parents of the most obese children.

Materials and methods

An exact assessment of assortative mating for obesity would require knowledge of weight and height of both partners at the time they originally met. Evidently, this cannot be achieved reliably in a retrospective study based on the offspring of such matings. In the light of this obstacle we chose a strategy which we consider as sufficient for a crude assessment of assortative mating. For study group 1 parental BMIs of 201 (100 males) independently ascertained children and adolescents with extreme obesity were calculated from measured height and weight. BMIs at ages 20 and 30, which are subsequently referred to as recalled BMIs were estimated for both parents based on recalled weights at these ages as obtained with a semistructured interview and measured current height. All 201 children had presented for inpatient treatment of their extreme obesity at the Children's Hospital Hochried in Murnau, Bavaria. The respective children and both of their parents had participated in a family study between 1995 and 1997; molecular genetic results of this ongoing study have been reported.^{5–9} Index patients and both parents were ascertained to enable association studies and tests for linkage disequilibrium. As such, obesity in sibs was not a selection criterion. Parents were specifically interviewed as to their biological relationship to the index patient. Based on our molecular genetic results we conclude that non-paternity is infrequent (rate below 5%).

Because the BMI is dependent on age and gender, BMI centiles were determined for both current BMIs and recalled BMIs of mothers and fathers at ages 20 and 30. The centiles are based on the German National Nutrition Survey^{10,11} and have been used for assessment of BMI increments of extremely obese children and adolescents between 1985 and 1995, who were also treated at the Children's Hospital Hochried,³ weight outcome in anorexia nervosa¹² and for evaluation of BMI of children and adolescents with specific psychopathological conditions.^{13,14} A specifically devised computer program is used to determine the respective centile on an individual basis. Absolute BMI values constituting specific centiles (including the 50th and 95th) at different ages have been delineated.¹¹ For the purpose of this study the absolute BMIs corresponding to the 90th centile are illustrated in Table 1.

The relevant demographic data of both the 201 index patients and their parents are shown in Table 2. Sixty-four of the index patients had a BMI below

the maximal BMI observed in the population based German National Nutrition Survey for the respective age in years and gender; 137 patients had a BMI equal to or in excess of these maximal BMIs. For the age range from 10 to 50y this survey was based on approximately 175–200 males and females, respectively, for each age span in years.¹¹

The current BMI centiles were calculated for all 201 mothers and fathers and attributed to the respective decile. However, only 153 parental pairs were interviewed as to their weights at ages 20 and 30. Because one or both of the parents were unable to recall their weights, centiles of only 133 and 132 parental pairs were available for the plots of deciles at ages 20 and 30, respectively. To crudely assess the extent of assortative mating, fathers' current BMI deciles and the BMI deciles at ages 20 and 30, respectively, based on recalled weights were plotted against the corresponding deciles of the mothers.

In order to attempt to replicate our results and to assess the effect of the extent of the obesity of the index patient we additionally referred to self-reported current body heights and weights of both parents of 270 (108 males) extremely obese children and adolescents subsequently referred to as study group 2. These parents had been asked to provide ages, weights, heights and gender of themselves and their offspring including the index patient prior to initiation of inpatient treatment at the Children's Hospital Hochried using a specifically devised questionnaire. Approximately 80% of the parents of consecutively admitted inpatients filled out this questionnaire. The index patients were subdivided into two subgroups a and b based on whether ($n = 142$) or not ($n = 128$) their BMI equalled or exceeded the maximal BMI observed in the population-based German National Nutrition Survey for the respective age in years and gender. The relevant anthropometric data for both subgroups are shown in Tables 3a and b.

Results

Obesity was commonly observed in both parents of the index patients (Figures 1–5). This effect was independent of the study group and independent of whether current BMIs or past recalled BMIs were assessed. Thus, in both study groups parents who both had a BMI in excess of the 90th centile proved to be the most frequent subgroup based on the division according to BMI deciles. It is of interest to note that in 25 of the 201 (12.4%) parental pairs of the first study group both mother and father had BMIs equal to or exceeding the 99th centile based on the German National Nutrition survey. All in all, a total of 37 (18.4%) fathers and 39 (19.4%) mothers in the first study group had a BMI \geq 99th centile.

In both study groups a very consistent pattern was observed for current BMIs in that in most families

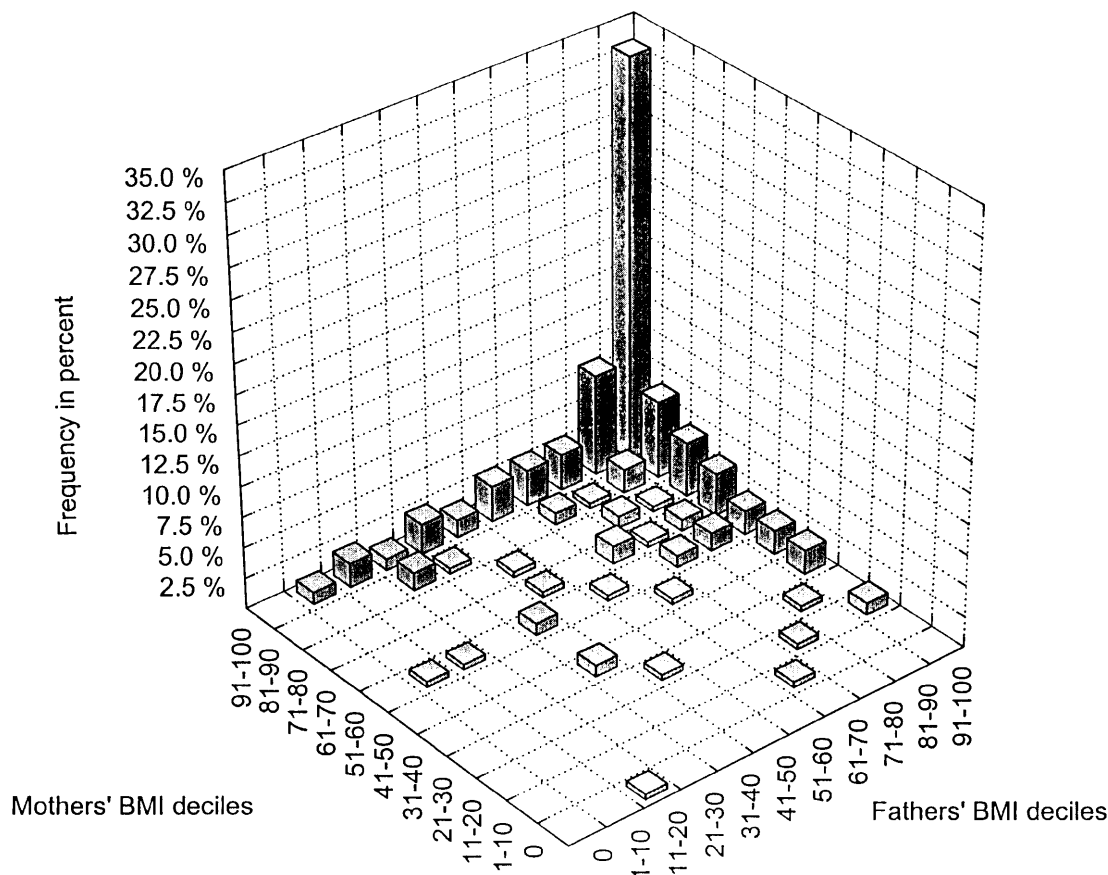


Figure 1 Bivariate histogram of population based BMI deciles of mothers and fathers of 201 children with extreme obesity (study group 1). Current heights and weights of the parents were measured to calculate BMIs and to determine BMI centiles.

either father, mother or both parents had a BMI > 90th centile (Figures 1, 4 and 5). Thus, in study group 1 a total of 110 fathers (54.7%) and 118 (58.7%) mothers had a BMI in the tenth decile (Figure 1). In 70 families (34.8%) both parents had a BMI corresponding to the tenth decile. In study group 2a (Figure 4), 69 (48.6%) and 58 (40.8%) of the 142 fathers and mothers had a BMI within the tenth decile. In 27 families (19.0%) both parents were within this decile.

Furthermore, it is noteworthy that stepwise increments of the observed frequencies are apparent as the tenth decile range of either parent is transversed (Figures 1–4). A deviation from this pattern was observed only for the parents of those children with a BMI below the 100th centile (study group 2b; Figure 5). Among these parents a clear clustering in the upper decile range was also evident. However, the marked loading on the tenth decile was less prominent. Thus, only 23.4% and 28.1% of the fathers and mothers, respectively, had a BMI corresponding to this decile. Both parents had a BMI within this decile in 13.3% of the families. In study group 2b (Figure 5) the higher frequencies in the lower decile ranges contrast to the almost complete absence of parental pairs

in this same range for children of study group 2a (Figure 4).

Figures 2 and 3 reveal that the general pattern based on recalled BMIs at ages 20 and 30 is similar to that observed for current BMIs (Figure 1). The highest loading was observed for the subgroup formed by those parents who both recalled having had BMIs > 90th centile at the respective ages. Furthermore, frequencies in the tenth decile of both genders clearly exceeded those of other deciles. In females a considerable loading was also apparent for the ninth decile. Amongst the mothers the occurrence of BMIs in the first decile is noteworthy.

Discussion

If within the past 20–25 years obese individuals have more frequently formed partnerships amongst each other than three or four decades ago, additive and non-additive genetic factors as well as non-genetic factors could imply a higher risk for the development of obesity in the respective offspring and as a conse-

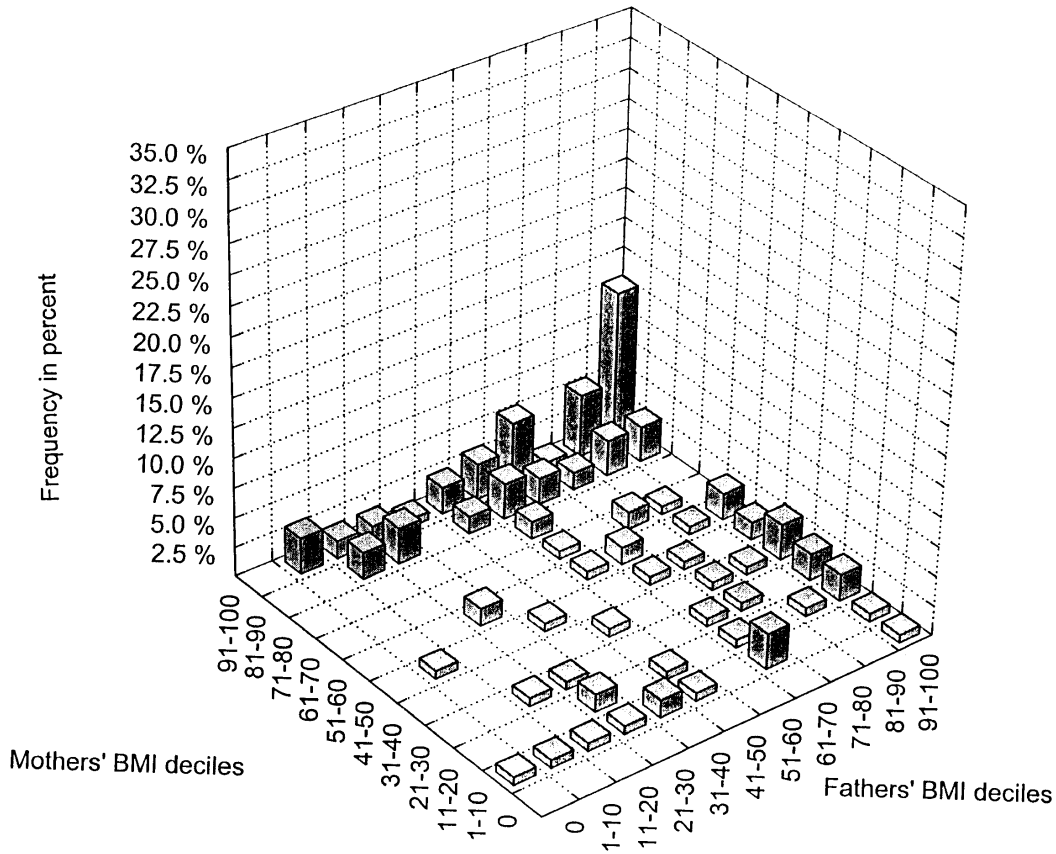


Figure 2 Bivariate histogram of population-based BMI deciles of mothers and fathers of 133 children with extreme obesity based on recalled weights at age 20 and measured current heights.

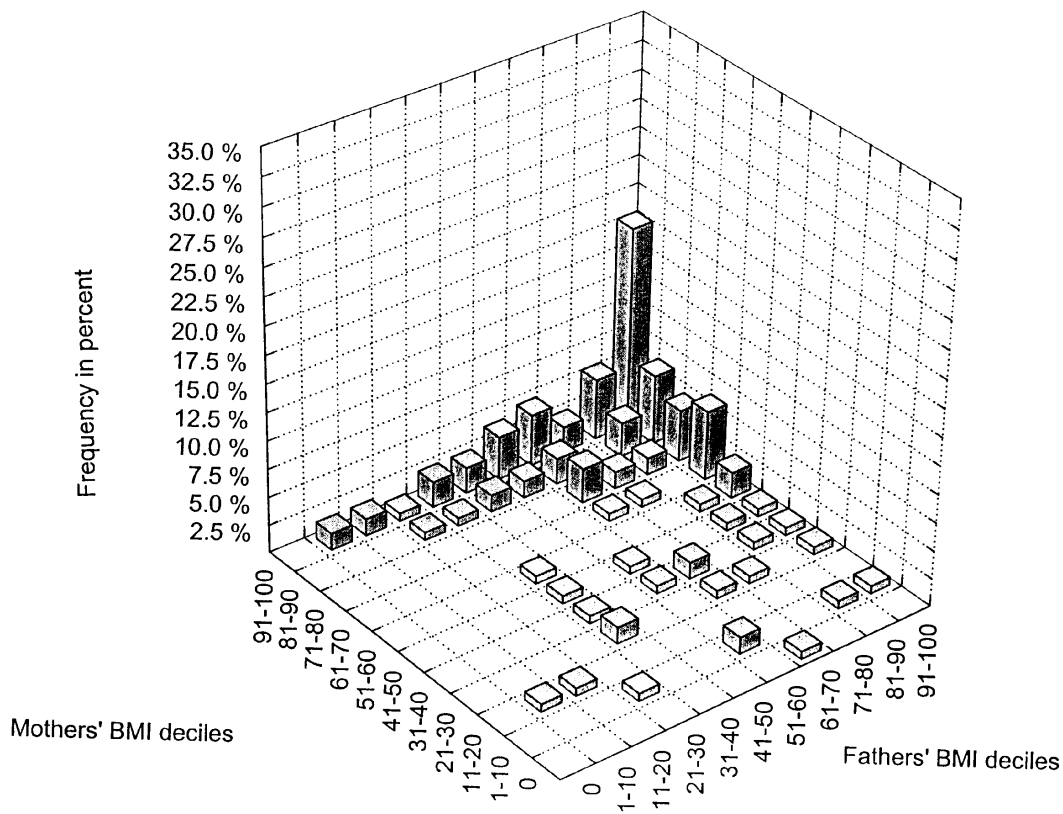


Figure 3 Bivariate histogram of population-based BMI deciles of mothers and fathers of 132 children with extreme obesity based on recalled weights at age 30 and measured current heights.

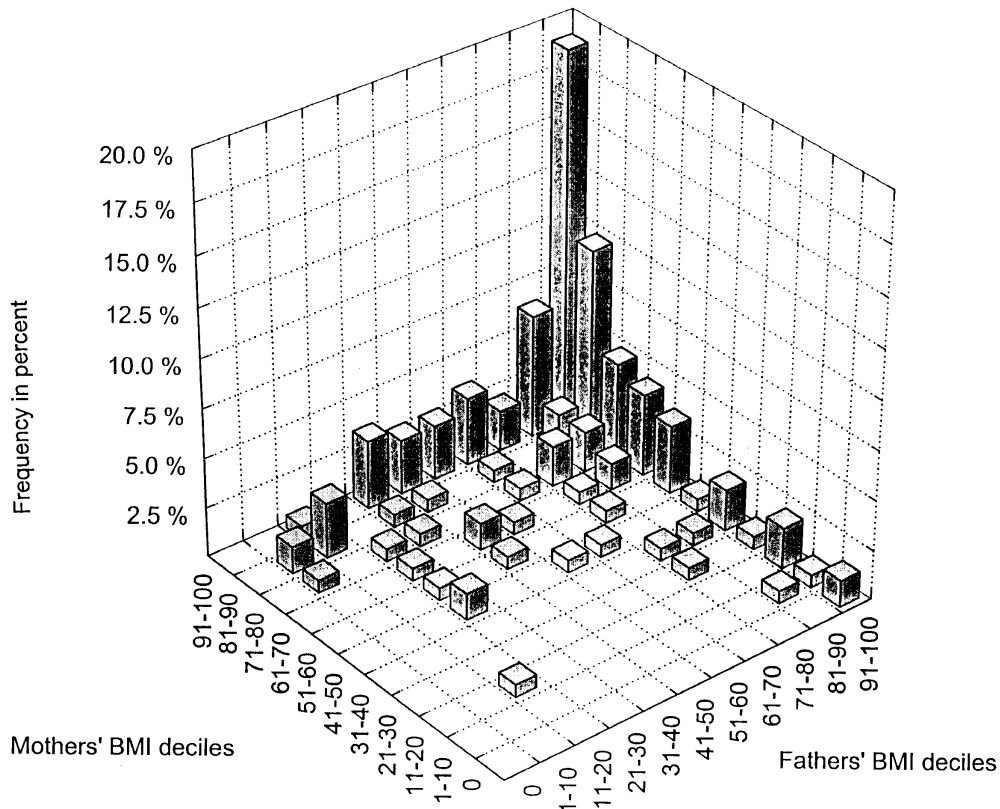


Figure 4 Bivariate histogram of population-based BMI deciles of mothers and fathers of 142 children with extreme obesity as defined by a BMI equal to or in excess of the maximal BMI of age and gender matched population controls. BMIs were calculated from self-reported current heights and weights to determine the corresponding BMI centiles.

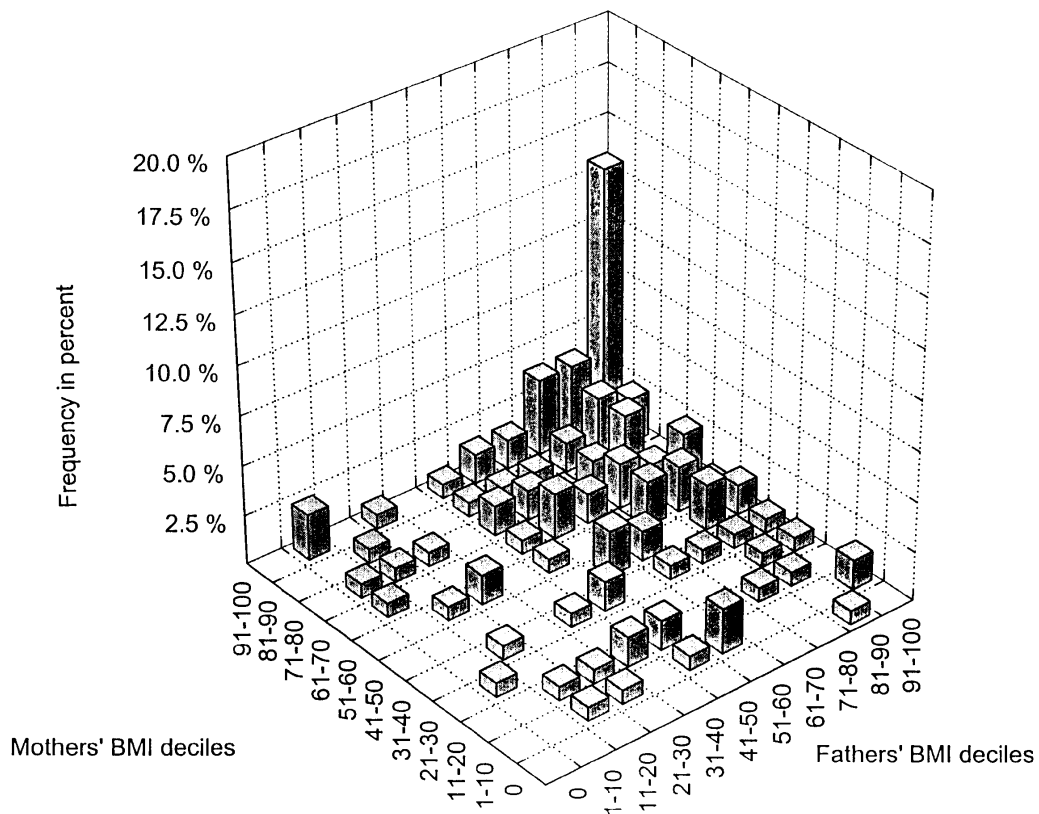


Figure 5 Bivariate histogram of population-based BMI deciles of mothers and fathers of 128 children with extreme obesity. The children had a BMI below the maximal BMI of age and gender matched population controls. BMIs were calculated from self-reported current heights and weights to determine the corresponding BMI centiles.

quence contribute to the observed recent increase of obesity rates in affluent societies. Furthermore, this effect would also have an impact on the degree of adiposity observed in the general population. Thus, based on quantitative genetic considerations offspring of two obese parents can be perceived as having a higher risk for severe obesity than offspring of non-obese parents or with only one obese parent.

As such it is conceivable that assortative mating in particular contributes to increased rates of severe obesity for which we have found indirect evidence in a cross-sectional study of obese children and adolescents who were treated at the Children's Hospital Hochried between 1985 and 1995,³ the same hospital from which the study groups analysed in this investigation stemmed. In this context it is worth mentioning that among US children and adolescents extreme obesity as defined by the 95th centile based on the NHES performed between 1963 and 1970 has nearly doubled in the past three decades, whereas the relative increase based on using the 85th centile as the cut-off has only amounted to 50%.²

It is important to realize that a postulated increase in assortative mating for obesity would imply increased rates and degrees of obesity not only via genetic factors. If both parents are obese, familial environmental effects favouring the development of obesity are also effective in the offspring. Nevertheless, in contrast to previous environmentally based hypotheses attempting to explain the increased rates of obesity in affluent countries we propose that genetic factors might very well have a contributing effect via increased rates of assortative mating. The fact that women who marry men of higher education are systematically leaner and women who marry men of lower education are both fatter and heavier¹⁵ suggests that assortative mating is a complex phenomenon encompassing aspects related to both body weight and socio-economic issues. Societal norms related to these and possibly other aspects are most likely to have an impact on assortative mating, especially for those individuals with an extremely high body weight.

Our hypothesis cannot be proven by the results obtained within this study, because we are unable to document an increased rate of assortative mating over the past two to four decades nor its effect on obesity rates. However, our data are fully compatible with the hypothesis in that, in two independent study groups, we show that parents of extremely obese children ascertained recently (between 1995 and 1997) are frequently both obese and that—despite the caveat that we do not precisely know at what ages the respective parents met and what their BMIs were at that time—obesity in both parents was also common within the age range that the mothers and fathers were likely to have met each other. Our data indicate that, as hypothesized, the (deduced) rate of assortative mating is higher in those parents of children with an extreme form of obesity than in parents of children with less extreme obesity (Figures 4 and 5).

Assortative mating for relative weight has been demonstrated previously.¹⁶ A small but nevertheless significant intermate correlation of approximately 0.1–0.25 is a consistent finding in those studies that have assessed relative weight. Even prior to marriage, mates have been shown to be correlated for relative weight after adjustments for age.¹⁶ However, this and similar studies specifically aimed to assess Pearson correlations in mates of different weight classes. In the present study we have attempted to deduce rates of assortative mating in parents of extremely obese children. We believe that the magnitude of assortative mating in parents of obese children is better assessed by defining thresholds and quantifying the proportion of matings in which both partners are above or below the respective threshold. Thus, in statistical terms the use of biserial correlations would appear more adequate. We argue that our hypothesis of a recent increase in assortative mating is especially relevant when offspring whose BMIs contribute to the extreme right side of the BMI distribution are assessed.

Unfortunately we do not have anthropometric data on parents of extremely obese children ascertained in past decades. We expect that assortative mating would not have been as common as indicated by the data analysed within this study. It should again be noted that the very extreme forms of obesity in particular have apparently increased in children and adolescents,³ thus perhaps virtually precluding a comparison based on age and gender matched BMIs of obese children. It would presumably have been very difficult to identify an equally large study group of children and adolescents matched for BMI 20 or more y ago.

A comparison of our data with former studies is rendered difficult by several aspects. For one, both BMI and BMI centiles were not used in older studies or reviews.^{18–26} Definitions of overweight and obesity were not always clearly delineated in the index patients and their relatives; the proportion of the general population that fulfilled the respective criteria was unknown or not reported. Assessments of weights of relatives were partially based on the family history method. In addition, data sets specifically applying to (extremely) obese children are rare. Delineation of assortative mating is also not satisfactorily addressed in some of these studies. In their 1934 study of 50 obese children Ellis and Tallermann²⁰ found 'one or more members of the immediate family affected in 30 out of the 50 cases. Of the parents, the mother, but not the father, was grossly overweight in 13 instances, the father, but not the mother, in 6, and both parents in 3'. Iversen in 1953²⁴ reported obesity in one or both parents of 31 children out of the total sample of 50 who were between 10% and 103% overweight. Obesity was present in both parents of 13 out of the 50 children. In more recent family studies rates of assortative mating are not delineated.^{27,28} In a large four generation Utah pedigree ascertained for a high load-

ing with morbid obesity a clear trend for increasing rates of assortative mating from the early to late generations was described.²⁹ In conclusion, the difficulties encountered upon our attempt to compare our results with past studies were insurmountable; only a precise delineation of the relevant data (Tables 1, 2, 3) will enable such valuable comparisons. Ideally, comparisons required to assess temporal changes in rates of assortative mating for obesity should be made within the same country.

An aspect that had already been documented early on deserves notice: matings between 'stout and stout' considerably more often resulted in stout offspring than those between 'stout and average' or 'average and average' matings.^{21,23,26} We were unable to find data showing that the obese children of two obese parents on average have a higher degree of adiposity than those obese children with only one obese parent. However, we assume that data of this kind have been compiled.

The recent increase of stigmatization of obese individuals in Western societies would appear to be the driving force behind the postulated increase in rates for assortative mating. In Germany data show that stigmatization increased considerably between 1971 and 1979; the negative ratings of obese individuals persisted in 1989.³⁰ In dominant American society, overweight and obesity are viewed as obvious symbols of an individual's moral failings in self-control. Discrimination is widespread, with 'fat-ism' being a socially tolerated prejudice of the 1990s, much as racism was prior to civil rights movement of the 1960s.³¹ Back in 1931 Dunlop and Lyon¹⁸ refer to the then 'popular conception of the stout person as an individual of an easy-going, equable disposition'. However, the 'pressure of modern fashion, which sends so many stout women to the physician' was already referred to by Gurney in 1936.²¹ These references have a mere anecdotal character; they cannot address the question of whether rates of assortative mating have been influenced by changing societal norms over the past decades. We are unaware of data of this kind.

Several minor issues pertaining to our study warrant attention. Assortative mating for obesity should ideally be assessed at the time partnerships evolve. Our study relies on current BMIs and recalled BMIs, which were assessed with population-based centiles. On an individual basis the BMI at age 20 fairly well predicts the BMI at age 40 and 50,³² so that it is safe to assume that many of the obese parents assessed in our study were indeed already obese at age 20. This is substantiated by the recalled BMIs at ages 20 and 30 (Figures 2 and 3). Recalled weights at ages 20 and 30 have been shown to be quite reliable.³³ It is interesting to note that at age 20 a subgroup of fathers and mothers both reported a BMI below the 50th centile. Possibly, especially among this subgroup, the respective weights were recalled wrongly. On the other hand it cannot be excluded that genetic

and non-genetic factors in parental pairs with adult onset obesity lead to an earlier onset in their offspring.

We referred to population-based BMI-centiles to assess deduced rates of assortative mating and to subgroup the severity of adiposity in study group 2. As such it is important to briefly review relevant aspects of the German National Nutrition Survey. It was based on 24,632 individuals living in 11,141 independent households who were contacted between 1985 and 1989. The survey was representative for social status, rural vs urban residency, and season of the year. Participants self-reported their weights and heights.¹² In the present investigation we analysed both measured (study group 1) and self-reported data (study group 2) based on index patients who were ascertained between 1995 and 1997. Despite potential problems inherent to basing a study on population-based controls we argue that the patterns observed in the bivariate histograms (Figures 1–5) are so clear cut that distortions due to methodological problems are most likely of a quantitative and not of a qualitative nature. Thus, to illustrate this point it seems quite plausible to assume that the higher rates of loading on the tenth BMI decile in study group 1 as compared to study group 2 reflect reliance on measured vs self-reported anthropometric data of the assessed parents. Nevertheless, the deduced trend towards assortative mating as a major contributing factor to the obesity observed in the extremely obese children and adolescents is readily apparent in both study groups.

Because most segregation studies have provided evidence for a major recessive gene effect,^{34,35} it is of interest to note that in our extremely obese study groups obesity in at least one of the two parents is present in most families, as illustrated by the strong loading on the tenth deciles (Figures 1 and 4). In our opinion, this parental loading renders dominant effects likely for extreme obesity; however, recessive effects could very well also apply. Recently, an assumed dominantly inherited form of obesity has been elucidated at the molecular level.^{7,36,37} Thus, mutations in the melanocortin-4 receptor gene leading to haploinsufficiency were found to occur with a frequency of about one percent among extremely obese children and adolescents.⁷

We conclude by stressing the importance of addressing a temporal increase of assortative mating as a possible contributing cause to the recent rise in obesity rates. It seems possible that this aspect can be investigated based on family data sets collected within a specific population over the past 30–40 y. We assume that assortative mating is especially relevant in explaining the increases of extreme forms of obesity. In studies related to the phenomenon of secular trends in assortative mating it is of utmost importance that the relevant anthropometric data are presented in a manner readily allowing comparisons.

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