

Estimated Risks for Developing Obesity in the Framingham Heart Study

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Background: The short- and long-term risks for developing overweight or obesity are unknown.

Objectives: To estimate the short-term, long-term, and lifetime risks for developing overweight or obesity in adults in the community.

Design: Prospective cohort study, 1971 to 2001.

Setting: Community-based study, Framingham, Massachusetts.

Participants: 4117 white participants (51.9% women) from the Framingham Heart Study.

Measurements: The short-term (4 years) and long-term (10 to 30 years) risks for ever becoming overweight or more (body mass index [BMI] ≥ 25 kg/m²) or obese (BMI ≥ 30 kg/m²) for men and women at 30, 40, and 50 years of age with a normal BMI (between 18.5 kg/m² and 25.0 kg/m²).

Results: The observed 4-year rates of developing overweight varied from 14% to 19% in women and 26% to 30% in men.

Four-year rates of developing obesity ranged from 5% to 7% in women and 7% to 9% in men. The long-term (30-year) risk estimates were similar for the 2 sexes generally; varied somewhat with age (in men, being lower for those 50 years of age); and, overall, exceeded 1 in 2 persons for overweight or more, 1 in 4 individuals for obesity, and 1 in 10 people for stage II obesity (BMI ≥ 35 kg/m²) across different age groups. The 30-year estimates correspond to the residual lifetime risk for overweight or more or obesity for participants 50 years of age.

Limitations: These findings may not be generalizable to other races or ethnicities.

Conclusions: The long-term risks for overweight or more or obesity exceeded 50% and 25%, respectively, indicating a large public health burden. These estimates suggest that the future burden of obesity-associated diseases may be substantial.

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Obesity, defined as a body mass index (BMI) of 30 kg/m² or more (1, 2), is a major public health problem that has reached epidemic proportions in the United States (3–7). Excess weight is associated with increased risk for cardiovascular disease, several forms of cancer, and death (8, 9). Combating obesity requires knowledge of the incidence, prevalence, and rates of transition between stages of the condition. Data on the prevalence of obesity (including secular trends) are readily available through serial national cross-sectional surveys (3–7). However, insufficient information is available on the short-term, age-conditional risk and the residual lifetime probability of becoming overweight or obese. The short-term, age-conditional risk estimates present people with risk information tailored to their age (10) and may encourage lifestyle changes in the short run. The residual lifetime risk statistic (the probability of developing a condition over the remainder of an individual's life) is easily understood by the general public and is more meaningful to health planners (11–14). Accordingly, we estimated the short-term (4 years), long-term (10 to 30 years), and lifetime risks for developing overweight or obesity by using longitudinal observations on a community-based sample.

METHODS

The design and selection criteria of the Framingham Offspring Study have been described previously (15). Participants in the study are examined approximately every 4 years. Individuals (men and nonpregnant women) were el-

igible for our investigation if they attended at least 2 routine examinations between 1971 and 2001 and were not underweight (BMI < 18.5 kg/m²). At each routine Framingham Offspring Study examination, investigators used a standardized protocol to measure height (to the nearest 0.25 inch) and weight (to the nearest pound) (16, 17). Investigators calculated BMI as the weight (kg) divided by height squared (m²). All participants gave written informed consent, and the institutional review board of the Boston Medical Center approved the study protocol.

Body Mass Index on Follow-Up: Definitions of Overweight and Obesity

We followed all eligible participants from the time of entry into the investigation until the end of the observation period, the development of overweight or obesity (the BMI outcomes of interest, as defined later), death (without obesity or the BMI outcome of interest), or the last follow-up

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Summary for Patients I-12

Web-Only

Appendix

Appendix Table

Conversion of figure and tables into slides

Context

What are the risks for becoming overweight or obese after age 30 years?

Contribution

This study tracked 4117 normal-weight white adults 30 to 59 years of age who participated in the Framingham Offspring Study during 1971 to 2001. Within 4 years, 14% to 19% of the women and 26% to 30% of the men became overweight and 5% to 9% of both groups became obese. Within 30 years, more than half of both groups became overweight and about one third of the women and one quarter of the men became obese.

Implications

Long-term risks for white U.S. adults developing obesity are very high.

—The Editors

examination. The World Health Organization (WHO) (2) provided a classification system for BMI that the National Institutes of Health (NIH) has adopted (1). A BMI between 18.5 kg/m² and 25.0 kg/m² is considered normal (1, 2). We examined the risk for development of the following states (BMI outcomes): overweight (BMI ≥ 25 kg/m² but <30 kg/m²), overweight or more (BMI ≥ 25 kg/m²), obesity (BMI ≥ 30 kg/m²), stage II obesity (BMI ≥ 35 kg/m² but <40 kg/m²), and stage III obesity (BMI ≥ 40 kg/m²).

Statistical Analysis**Short-Term (4 Years) Rates of Developing Overweight or Obesity**

Participants who attended 2 or more consecutive examinations approximately 4 years apart were eligible for these computations. Participants attending the first examination (in 1971) were not eligible for these analyses because the second examination was 8 years later (in 1979). We categorized participants into 10-year age groups, that is, ages 30 to 39 years, 40 to 49 years, and 50 to 59 years (called baseline ages). We constructed sex-specific transition matrices by cross-tabulating each participant's BMI category at the beginning of the 4-year observation period against his or her BMI at the end of that period. For each age group, we estimated crude sex-specific incidence rates of overweight and obesity for participants without the condition (overweight or obesity) at baseline. Participants were eligible for inclusion at more than 1 examination cycle if they reached the next examination without overweight or obesity (for analyses of new-onset overweight) or obesity (for analyses of new-onset obesity).

Errors in measurement of BMI can influence incidence rates of overweight or obesity because individuals with BMI values close to the chosen thresholds (25 kg/m² or 30 kg/m²) may be categorized as having become overweight or obese simply because of small variations in BMI

that may not represent true change (18). Therefore, we repeated our analyses with the additional requirement that an individual should change BMI by at least 0.5 kg/m² over 4 years to qualify for a change in BMI category.

Short-term rates of development of overweight or obesity also may be sensitive to weight cycling. Accordingly, we tested the sensitivity of our short-term estimates of incidence of overweight or obesity by performing analyses that excluded individuals with potential mild or greater weight cycling (≥3 episodes of gain or loss of 10 pounds [4.5 kg] of weight before the baseline age [that is, before the observation period] [19]).

Smoking status and smoking cessation have been reported to influence weight gain (20, 21). Therefore, we evaluated the sensitivity of our short-term risk estimates to the inclusion of smokers in the sample by repeating our analyses in a subsample of individuals who never smoked (or never smokers) before and at the baseline age and during follow-up. In addition, because obesity rates have increased considerably over the past 3 decades (3–6, 22), we repeated our analyses by deriving our risk estimates from individuals who attended 2 consecutive examinations between 1991 and 2001 (examination cycles 5 [1991 to 1994] through 7 [1998 to 2001]). Since individuals could contribute to more than 1 baseline age group in primary analyses, we repeated analyses with the additional constraint that individuals could contribute only once during the period of observation (to the first eligible age group).

Long-Term (10 to 30 Years) Risk and Residual Lifetime Risk for Ever Developing New-Onset Overweight or More and Obesity in Individuals without the Conditions at Baseline

We estimated the long-term (10 to 30 years) risks for ever becoming overweight or more or obese (including different stages of obesity) for study participants without the condition of interest who attended at least 2 examinations during the time period (1971 to 2001). Participants who attended the first examination (in 1971) were eligible for these analyses (though not for the analyses of short-term risk estimates) because attendance of consecutive examinations 4 years apart is not required for long-term risk estimation.

We categorized participants into 5-year age groups: 30 to 34 years, 35 to 39 years, 40 to 44 years, 45 to 49 years, 50 to 54 years, and 55 to 59 years. We constructed 5-year age groups (as opposed to 10-year age groups for short-term risks) because narrower age groups are optimal for use with the Practical Incidence Estimators macro (11) that we used for risk estimation. We performed sex-specific analyses separately for the baseline age groups and for each BMI outcome. For the sake of simplicity, we present only estimates for baseline ages 30 to 34 years, 40 to 44 years, and 50 to 54 years. Because we have approximately 30 years of follow-up data for the offspring cohort, we estimated the risk for developing BMI outcomes through age 60 to 64

years for participants 30 to 34 years of age, through age 70 to 74 years for participants 40 to 44 years of age, and through age 80 to 84 years for participants 50 to 54 years of age. The 30-year estimate for baseline age of 50 to 54 years approximates the residual lifetime risk (that is, cumulative risk over remaining lifetime) for any BMI outcome.

For calculating long-term and lifetime risks for ever developing each BMI outcome, we used a modified technique of survival analysis adjusted for competing risk for death (with the Practical Incidence Estimators macro, detailed elsewhere [11]; see Appendix, available at annals.org, for details and model assumptions). For example, to estimate the cumulative incidence of obesity by age 60 years for participants entering the study without the condition at 40 years of age, we would add the probabilities of becoming obese between ages 40 and 41 years, 41 and 42 years, and so on up to ages 59 and 60 years. All long-term risk estimates presented in our report are adjusted for mortality. Individuals could contribute to more than 1 baseline age group. We repeated analyses with the additional requirement that individuals could contribute only to 1 age group: the first age group that they were eligible for during the observation period.

The aforementioned techniques estimate risk for ever developing obesity but may overestimate risk because obe-

sity may not be a permanent state (23, 24). Therefore, we conducted secondary analysis with “sustained” obesity as an outcome of interest. Sustained obesity was defined as a BMI of 30 kg/m² or greater at 2 consecutive Framingham Offspring Study examinations. Only participants with 2 sets of 2 consecutive examinations were eligible for this analysis. We also assessed the long-term and lifetime risk for overweight or more or obesity in never smokers.

Long-Term Risk and Residual Lifetime Risk for Ever Developing New-Onset Overweight or More and Obesity in Individuals, Accounting for Prevalence at Baseline Age

Long-term risk measures derived by using aforementioned methods work well for estimating public health burden when conditions do not occur in young adulthood (such as Alzheimer disease [13]). However, overweight and obesity are widely prevalent in young adults. To account for the presence of overweight or obesity at a baseline age, we adjusted our long-term risk estimates by changing the starting probability of survival from 1 to (1 – baseline prevalence rate) in the Practical Incidence Estimators macro. This modification requires an adjustment to the CIs produced to account for the variability of both the long-term risk estimates and baseline rate. This can be ac-

Table 1. Change in Body Mass Index Category on 4-Year Follow-Up according to Baseline Body Mass Index Category*

Baseline BMI Category	BMI Category on Follow-Up, n (%)					
	Women			Men		
	Normal	Overweight	Obese	Normal	Overweight	Obese
Entire sample						
Age 30–39 y						
Normal	662 (85.6)	109 (14.1)	2 (0.3)	222 (70.5)	92 (29.2)	1 (0.3)
Overweight	39 (17.3)	135 (60.0)	51 (22.7)	46 (9.8)	371 (78.6)	55 (11.6)
Age 40–49 y						
Normal	1176 (80.0)	284 (19.3)	10 (0.7)	388 (72.5)	144 (26.9)	3 (0.6)
Overweight	66 (10.1)	458 (69.8)	132 (20.1)	75 (6.3)	961 (80.8)	153 (12.9)
Age 50–59 y						
Normal	971 (81.6)	216 (18.2)	2 (0.2)	398 (73.4)	141 (26.0)	3 (0.6)
Overweight	100 (10.8)	678 (73.0)	151 (16.2)	91 (7.2)	1018 (80.9)	150 (11.9)
Nonsmokers only						
Age 30–39 y						
Normal	472 (84.7)	83 (14.9)	2 (0.4)	145 (70.7)	59 (28.8)	1 (0.5)
Overweight	28 (18.4)	89 (58.6)	35 (23.0)	37 (10.3)	281 (77.8)	43 (11.9)
Age 40–49 y						
Normal	882 (81.7)	191 (17.7)	7 (0.6)	254 (70.8)	102 (28.4)	3 (0.8)
Overweight	42 (8.7)	333 (68.9)	108 (22.4)	52 (5.8)	731 (82.0)	109 (12.2)
Age 50–59 y						
Normal	732 (80.0)	182 (19.9)	1 (0.1)	294 (73.3)	106 (26.4)	1 (0.3)
Overweight	74 (10.1)	539 (73.2)	123 (16.7)	66 (6.5)	830 (81.6)	121 (11.9)
Examinations during 1990s†						
Age 40–49 y						
Normal	314 (79.3)	77 (19.4)	5 (1.3)	99 (72.8)	36 (26.5)	1 (0.7)
Overweight	12 (5.7)	160 (75.8)	39 (18.5)	18 (5.4)	272 (81.7)	43 (12.9)
Age 50–59 y						
Normal	382 (82.7)	80 (17.3)	0 (0.0)	138 (73.4)	48 (25.5)	2 (1.1)
Overweight	42 (10.1)	300 (72.3)	73 (17.6)	21 (4.2)	424 (83.6)	62 (12.2)

* Participants attended 2 consecutive examinations 4 years apart. BMI = body mass index.

† Numbers of participants in age group of 30–39 years were insufficient during examination cycles 5–7.

completed by applying the Δ method to calculate the standard errors of point estimates (25).

We performed all analyses with SAS, version 8 (SAS Institute, Cary, North Carolina).

Role of the Funding Sources

The National Institutes of Health and National Heart, Lung, and Blood Institute partly funded our study. The funding sources had no role in the design, conduct, or reporting of the study or in the decision to submit the report for publication.

RESULTS

Short-Term Incidence Rates of Overweight and Obesity

Between 1979 and 2001, 3710 unique individuals (1953 women) attended at least 2 consecutive examinations 4 years apart. Table 1 presents the changes in BMI categorization on follow-up for men and women in the sample, according to their baseline BMI category for different age groups. Among participants with normal BMI, 14% to 19% of women and 26% to 30% of men progressed to overweight over 4 years. Less than 1% of women and men with a normal BMI progressed to obesity over 4 years. Among overweight individuals, about 16% to 23% of women and 12% to 13% of men progressed to obesity over 4 years. When we considered people with normal BMI or overweight together, the 4-year rates of developing obesity varied from 5% to 7% in women and from 7% to 9% in men.

In the analyses of short-term risk for overweight or obesity, we categorized 2.8% of women and 2.0% of men as potential mild weight cyclers. Exclusion of all potential weight cyclers did not alter our estimates of short-term risks for overweight or obesity (data not shown). Likewise, when we required a change in BMI of at least 0.5 kg/m² over 4 years for people to change BMI categories, we obtained rates that were very similar to those displayed in Table 1 (data not shown).

Analyses restricted to never smokers and participants attending examinations between 1991 and 2001 yielded short-term transition rates that were very similar to those observed for the entire sample (Table 1). Estimates of short-term risk for overweight or obesity also remained unchanged in analyses performed with the additional con-

straint that individuals could contribute only once during the observation period (to the first eligible age group).

Long-Term and Lifetime Risk for Ever Developing Overweight or More or Obesity, Conditional on Survival without the Condition up to a Given Age

We investigated 4117 unique individuals (2137 women) for long-term risk for overweight or obesity. The sample size exceeds the 3710 individuals who contributed to short-term risk estimates because attendance at consecutive examinations 4 years apart was not required, as noted previously. Table 2 displays the proportions of men and women who attained a baseline age and who were overweight or obese. A higher percentage of men were overweight or obese compared with women at each baseline age group evaluated (with the exception of stages II and III obesity, which were more common in women).

Table 3 displays the long-term (10- to 30-year) mortality-adjusted risk for ever developing overweight or more or obesity, conditional on survival without the condition up to the baseline age. Over a follow-up period of 10 years, between 8% and 21% of women and 16% and 23% of men developed new-onset overweight or more, whereas 3% to 9% of women and 5% to 8% of men developed obesity. During 30 years of follow-up, more than half of women and men developed new-onset overweight or more and about one third of women and one quarter of men became obese (Figure). Long-term rates of overweight and obesity were lower for men 50 to 54 years of age relative to the younger age groups. The 30-year risk for developing stage II obesity (≥ 35 kg/m²) ranged from 11.0% to 13.0%, whereas it varied from 2.5% to 6.0% for stage III obesity (≥ 40 kg/m²). If mortality due to competing causes is ignored, risk estimates were slightly higher (data not shown).

When we repeated analyses to evaluate risk for "sustained" obesity (BMI ≥ 30 kg/m² at 2 consecutive examinations), estimates for long-term risk did not change in men but decreased modestly in women (Appendix Table, available at www.annals.org). Analyses restricted to never smokers yielded long-term estimates that were remarkably similar to those observed for the entire sample (data not shown). Estimates also remained unchanged in analyses performed with the additional constraint that individuals

Table 2. Proportions of Women and Men with Normal Body Mass Index, Overweight, and Obesity at Baseline Age*

Adiposity Stage	Women, %			Men, %		
	Age 30–34 y	Age 40–44 y	Age 50–54 y	Age 30–34 y	Age 40–44 y	Age 50–54 y
Normal	72.9	57.5	42.5	29.1	20.6	16.2
Overweight	17.7	26.1	34.0	52.8	55.6	52.5
Obese	9.4	16.4	23.5	18.1	23.8	31.3
Stage II	3.8	6.4	8.0	3.8	4.7	7.0
Stage III	1.0	2.7	3.8	0.4	0.9	2.0

* Women contributing to information for different age groups are as follows: age 30–34 y (*n* = 809), age 40–44 y (*n* = 1431), and age 50–54 y (*n* = 1680). Men contributing to information for different age groups are as follows: age 30–34 y (*n* = 704), age 40–44 y (*n* = 1294), and age 50–54 y (*n* = 1560).

Table 3. Long-Term Risk for Ever Developing Overweight or More and Obesity: Estimates Conditional on Survival without Overweight or Obesity up to Baseline Age*

Years from Baseline	Risk for BMI Outcome (95% CI), %					
	Women			Men		
	Age 30–34 y at Baseline	Age 40–44 y at Baseline	Age 50–54 y at Baseline	Age 30–34 y at Baseline	Age 40–44 y at Baseline	Age 50–54 y at Baseline
Risk for developing overweight or more						
10	8.0 (5.7–10.2)	17.8 (15.0–20.5)	20.8 (17.2–24.3)	15.7 (10.5–20.8)	23.2 (17.7–28.5)	19.4 (13.3–24.8)
15	22.4 (18.9–25.9)	35.1 (31.4–38.6)	35.6 (31.0–40.1)	37.0 (30.0–43.9)	33.8 (27.5–39.9)	30.2 (22.9–36.9)
20	37.7 (33.4–41.9)	50.6 (46.4–54.7)	47.7 (42.2–52.8)	55.2 (47.8–62.5)	50.5 (43.0–57.7)	40.5 (31.5–48.5)
25	50.5 (45.9–55.1)	60.6 (55.9–65.1)	50.7 (44.8–56.2)	64.1 (56.6–71.7)	58.0 (50.0–65.6)	48.0 (36.4–57.5)
30	63.9 (58.2–69.6)	68.7 (63.4–73.9)	55.5 (47.5–62.7)	73.2 (65.0–81.5)	60.9 (52.4–69.0)	48.0 (36.4–57.5)
Risk for developing obesity						
10	2.9 (1.6–4.1)	5.8 (4.4–7.2)	8.6 (6.8–10.4)	4.5 (2.7–6.2)	7.9 (6.1–9.7)	7.1 (5.2–8.9)
15	8.4 (6.2–10.4)	13.2 (11.0–15.3)	16.2 (13.5–18.7)	10.0 (7.4–12.5)	15.4 (12.8–17.9)	13.1 (10.3–15.6)
20	15.0 (12.1–17.8)	20.3 (17.5–23.1)	24.3 (20.6–27.7)	19.8 (16.2–23.3)	22.9 (19.6–26.1)	18.2 (14.6–21.4)
25	22.0 (18.5–25.5)	26.8 (23.2–30.2)	28.9 (24.2–33.2)	28.3 (23.9–32.6)	29.6 (25.4–33.4)	24.2 (19.0–28.5)
30	32.1 (27.1–36.9)	34.9 (29.8–39.8)	32.6 (26.6–38.0)	36.2 (30.4–41.7)	32.9 (27.9–37.4)	25.9 (19.3–31.3)
Risk for developing stage II obesity or more						
10	1.1 (0.3–1.8)	2.6 (1.7–3.5)	3.2 (2.1–4.2)	1.2 (0.4–2.1)	2.1 (1.2–2.9)	3.0 (1.9–4.0)
15	3.1 (1.8–4.3)	4.8 (3.5–6.0)	5.7 (4.1–7.2)	2.9 (1.5–4.2)	4.5 (3.1–5.8)	5.3 (3.7–6.7)
20	5.8 (4.0–7.5)	8.5 (6.5–10.2)	8.3 (6.1–10.4)	5.3 (3.4–7.1)	7.1 (5.3–8.9)	5.8 (4.1–7.4)
25	8.6 (6.3–10.9)	10.4 (8.1–12.7)	9.0 (6.3–11.5)	9.3 (6.6–11.9)	10.6 (7.8–13.2)	6.7 (4.6–8.6)
30	12.4 (9.1–15.6)	13.3 (9.9–16.6)	12.9 (8.3–17.0)	12.5 (8.9–15.9)	12.4 (8.8–15.7)	11.3 (3.2–17.4)
Risk for developing stage III obesity or more						
10	0.4 (0.0–0.8)	1.2 (0.6–1.8)	0.9 (0.3–1.4)	0.7 (0.1–1.4)	0.8 (0.3–1.3)	1.1 (0.4–1.7)
15	2.2 (1.1–3.2)	2.3 (1.4–3.2)	1.9 (1.0–2.8)	1.0 (0.3–1.8)	2.1 (1.2–3.0)	1.5 (0.7–2.3)
20	3.1 (1.8–4.4)	3.2 (2.0–4.3)	2.5 (1.3–3.6)	2.0 (0.8–3.1)	3.3 (2.0–4.5)	1.9 (0.8–2.8)
25	4.3 (2.7–5.9)	3.8 (2.5–5.1)	4.3 (1.9–6.5)	3.4 (1.7–5.0)	3.6 (2.1–4.9)	2.5 (1.0–3.7)
30	5.1 (3.2–6.9)	5.0 (3.0–6.9)	4.3 (1.9–6.5)	5.5 (2.9–8.0)	4.5 (2.5–6.2)	2.5 (1.0–3.7)

* People without obesity (i.e., BMI < 25 kg/m² plus overweight) contributing to information for different age groups are as follows: for women, age 30–34 y (*n* = 733), age 40–44 y (*n* = 1195), age 50–54 y (*n* = 1280); for men, age 30–34 y (*n* = 576), age 40–44 y (*n* = 982), age 50–54 y (*n* = 1070). Person-years of observation are as follows: for women, age 30–34 y (13 880 person-years), age 40–44 y (17 458 person-years), age 50–54 y (13 054 person-years); for men, age 30–34 y (10 436 person-years), age 40–44 y (13 928 person-years), age 50–54 y (11 250 person-years). Estimates are not directly comparable to short-term estimates in Table 1 because of differences in samples. BMI = body mass index.

could contribute only once during the observation period (to the first eligible age group).

Long-Term and Lifetime Risk for Ever Developing Overweight or More or Obesity, Accounting for Prevalence at a Given Age

Table 4 shows the mortality-adjusted risks for developing overweight or more or obesity over 10 to 30 years, taking into consideration that some people had already developed the outcome at the baseline age. More than half of women 40 to 44 years of age and about two thirds of those 50 to 54 years of age were overweight already or were likely to become overweight or more over a 10-year period from the baseline age. About 85% of men 40 to 44 years of age or older were or were likely to become overweight or more over a 10-year period. Between 12% and 30% of women and 22% and 36% of men were obese or developed obesity over a 10-year period (lower estimates indicating values for younger age groups).

Over a follow-up period of 30 years, more than three quarters of women and 90% of men were overweight or became overweight or more (Table 4). During this period, between 40% and 50% of participants were obese or de-

veloped obesity (Table 4). The mortality-adjusted 30-year risk for having or developing stage II obesity (≥ 35 kg/m²) ranged from 16% to 21%, whereas estimates for stage III obesity (≥ 40 kg/m²) varied from 4% to 8% (Table 4). If mortality due to competing causes is ignored, risk estimates were slightly higher (data not shown).

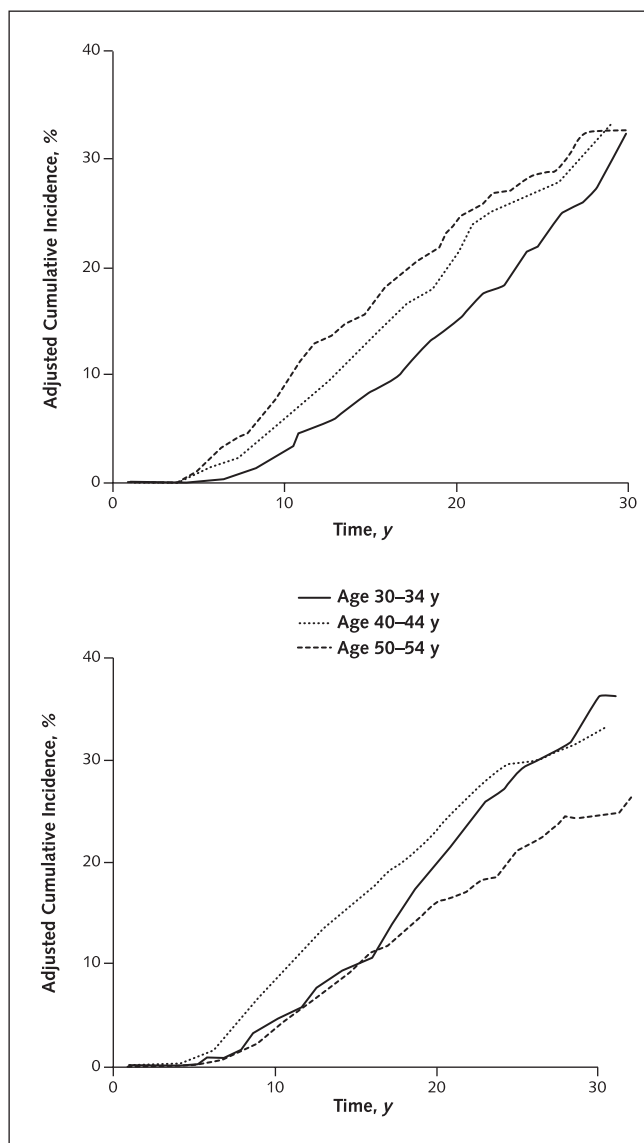
DISCUSSION

Principal Findings

In our community-based sample of young to middle-aged adults, roughly between one tenth and one quarter of individuals with normal BMI became overweight and a similar proportion of overweight people developed obesity over a 4-year period. Not surprisingly, the baseline BMI category was a critical determinant of risk for progression to obesity in the short run. The risk for obesity was substantially greater for overweight participants.

The long-term (10 to 30 years) risk estimates were similar for the 2 sexes generally; varied modestly with age (being lower for those 50 years of age); and overall, exceeded 1 in 2 persons for overweight or more, 1 in 4

Figure. Mortality-adjusted cumulative incidence rates of obesity for women (top) and men (bottom) for different age groups.



Data are for people free of obesity at baseline.

individuals for obesity, and 1 in 10 people for stage II obesity ($\text{BMI} \geq 35 \text{ kg/m}^2$) across different age groups. These estimates approximate data from cross-sectional surveys (4–6).

Our estimates accounting for baseline prevalence suggest that the 30-year risk for ever being overweight or more roughly exceeds 8 in 10 individuals, whereas that for obesity approximates 1 in 2 people. These estimates are higher than prevalence estimates based on national surveys (4–6).

Comparison with the Published Literature

Some previous investigations have evaluated the short-term risks for overweight or obesity (18, 26, 27). Rookus and colleagues (18) evaluated longitudinal changes in BMI in a sample of young Dutch individuals by using BMI cut-points and follow-up duration that were similar to

those in our study. The 4-year incidence rates of overweight were lower (for example, for age 30 years, 5.5% in women and 15.2% in men) than those in our investigation (18). Differences in time periods of the studies (the Dutch study was conducted between 1980 and 1984) and inherent characteristics of the samples may account for these differences. Comparing our results with those of other reports (26, 27) is difficult because they used different BMI cut-points.

Ten- and twenty-year longitudinal changes in weight have been reported on the basis of follow-up of individuals who were initially examined in the first National Health and Nutrition Examination Survey (NHANES) (24, 28, 29). A direct comparison of our results with the National Health Examination Follow-up Study (NHEFS) investigations is not possible because the 10-year reports (28, 29) used different BMI cut-points for defining overweight and obesity and the 20-year follow-up investigation (24) focused on changes in self-reported weight within BMI categories but did not provide data on actual BMI change. Longitudinal observations from the National Longitudinal Survey of Youth 1979 (30) provide valuable data on the 20-year incidence of obesity in young persons (17 to 18 years of age). Data for white participants in that study approximate the 20-year risk for obesity observed in individuals 30 years of age in our sample.

Strengths and Limitations

Our study is based on the longitudinal surveillance of the same community-based cohort over 30 years. During this time, we obtained BMI measurements every 4 years by using a standardized protocol. We acknowledge several limitations of our approach. First, we used BMI as an index of excess adiposity. Although such an approach is consistent with national guidelines and is simple, changes in BMI may not indicate alterations in body fat, especially in elderly people (31). Thus, individuals in their 70s lose lean body mass, consequently have a greater fat mass, and yet maintain their BMI at a constant level. Second, we did not investigate the development of patterns of overweight or obesity. Individuals may undergo redistribution of fat (such as increased abdominal obesity) without a change in weight or BMI. Third, we investigated individuals between 30 and 59 years of age. The actual long-term and short-term risks for overweight or obesity may differ for age groups younger or older than those investigated. Furthermore, our risk data are average estimates for study participants. The risk for overweight or obesity for a given individual will vary depending on the presence or absence of risk factors (such as dietary caloric intake, physical activity, family history of obesity, socioeconomic status, education level, cigarette smoking, alcohol consumption, and race or ethnicity).

In addition, we derived estimates on the basis of examinations conducted over 3 decades, during which obesity rates have increased considerably (3–6, 22). Our long-

Table 4. Long-Term Risk for Ever Being Overweight or More or Obese: Estimates Accounting for Presence of Overweight or Obesity at Baseline Age*

Years from Baseline	Risk for BMI Outcome (95% CI), %					
	Women			Men		
	Age 30–34 y at Baseline	Age 40–44 y at Baseline	Age 50–54 y at Baseline	Age 30–34 y at Baseline	Age 40–44 y at Baseline	Age 50–54 y at Baseline
Risk for developing overweight or more						
10	32.9 (29.6–36.1)	52.7 (50.1–55.3)	66.3 (64.0–68.7)	75.5 (72.3–78.7)	84.2 (82.2–86.2)	87.0 (85.3–88.7)
15	43.4 (39.9–46.9)	62.6 (60.0–65.3)	72.6 (70.2–75.1)	81.7 (78.7–84.6)	86.4 (84.5–88.3)	88.7 (87.1–90.4)
20	54.6 (50.9–58.2)	71.6 (68.9–74.3)	77.8 (75.2–80.3)	86.9 (84.3–89.6)	89.8 (88.0–91.7)	90.4 (88.7–92.1)
25	63.9 (60.2–67.6)	77.3 (74.5–80.1)	79.1 (76.4–81.7)	89.5 (87.0–92.1)	91.4 (89.5–93.2)	91.6 (89.8–93.4)
30	73.7 (69.5–78.0)	82.0 (78.9–85.1)	81.1 (77.8–84.3)	92.2 (89.6–94.8)	92.0 (90.1–93.8)	91.6 (89.8–93.4)
Risk for developing obesity						
10	12.0 (9.7–14.2)	21.2 (19.1–23.3)	30.1 (27.8–32.4)	21.8 (18.7–24.8)	29.8 (27.3–32.4)	36.2 (33.7–38.6)
15	17.0 (14.3–19.6)	27.4 (25.0–29.9)	35.9 (33.3–38.5)	26.2 (22.9–29.5)	35.5 (32.8–38.3)	40.3 (37.6–42.9)
20	23.0 (19.9–26.0)	33.4 (30.6–36.2)	42.0 (39.0–45.1)	34.3 (30.6–38.0)	41.3 (38.3–44.3)	43.8 (40.9–46.7)
25	29.4 (25.8–32.9)	38.8 (35.5–42.0)	45.6 (42.0–49.2)	41.3 (37.2–45.3)	46.3 (43.0–49.7)	47.9 (44.4–51.4)
30	38.5 (33.9–43.0)	45.6 (41.3–49.8)	48.4 (44.0–52.8)	47.7 (42.8–52.6)	48.9 (45.0–52.7)	49.1 (45.0–53.2)
Risk for developing stage II obesity or more						
10	4.9 (3.4–6.4)	8.8 (7.3–10.3)	11.8 (10.1–13.4)	5.0 (3.4–6.7)	6.6 (5.2–8.0)	9.8 (8.2–11.3)
15	6.8 (5.0–8.5)	10.8 (9.1–12.5)	14.1 (12.2–15.9)	6.6 (4.7–8.5)	8.9 (7.3–10.6)	11.9 (10.1–13.7)
20	9.4 (7.3–11.5)	14.3 (12.2–16.4)	16.4 (14.1–18.7)	8.9 (6.7–11.1)	11.5 (9.5–13.4)	12.4 (10.5–14.3)
25	12.1 (9.6–14.6)	16.1 (13.7–18.5)	17.0 (14.5–19.6)	12.8 (9.9–15.6)	14.8 (12.2–17.4)	13.3 (11.2–15.4)
30	15.8 (12.5–19.0)	18.9 (15.6–22.1)	20.6 (16.7–24.5)	15.9 (12.4–19.4)	16.5 (13.3–19.8)	17.5 (11.7–23.3)
Risk for developing stage III obesity or more						
10	1.4 (0.6–2.2)	3.8 (2.8–4.8)	4.7 (3.6–5.7)	1.2 (0.4–2.0)	1.7 (1.0–2.4)	3.1 (2.2–4.0)
15	3.1 (1.9–4.4)	4.9 (3.7–6.1)	5.7 (4.4–6.9)	1.5 (0.6–2.4)	3.0 (2.0–4.0)	3.5 (2.5–4.5)
20	4.0 (2.6–5.5)	5.7 (4.4–7.1)	6.2 (4.8–7.6)	2.4 (1.2–3.6)	4.2 (2.9–5.5)	3.8 (2.7–5.0)
25	5.2 (3.5–6.9)	6.4 (4.9–7.9)	8.0 (5.7–10.2)	3.8 (2.2–5.4)	4.5 (3.1–5.9)	4.4 (3.0–5.8)
30	6.1 (4.1–8.0)	7.6 (5.6–9.6)	8.0 (5.7–10.2)	5.9 (3.4–8.4)	5.3 (3.5–7.2)	4.4 (3.0–5.8)

* Women contributing to information for different age groups are as follows: age 30–34 y ($n = 809$), age 40–44 y ($n = 1431$), and age 50–54 y ($n = 1680$). Men contributing to information for different age groups are as follows: age 30–34 y ($n = 704$), age 40–44 y ($n = 1294$), and age 50–54 y ($n = 1560$). Person-years of observation are as follows: for women, age 30–34 y (15 896 person-years), age 40–44 y (21 040 person-years), age 50–54 y (16 824 person-years); for men, age 30–34 y (13 770 person-years), age 40–44 y (19 153 person-years), age 50–54 y (16 006 person-years). BMI = body mass index.

term risk estimates may be more conservative for this reason. We note, however, that about three quarters of observations of individuals 40 and 50 years of age were made at examinations in the late 1980s and 1990s, suggesting that our findings reflect contemporary experience overall. Our analytic method pooled estimates at each baseline age on the basis of participants attending an examination at that age (regardless of the calendar decade of attendance). Consequently, people from different birth cohorts probably contributed to observations for each baseline age, and birth cohort effects related to propensity for overweight or obesity have been described (30). This limitation is unavoidable because we estimated the long-term and lifetime risks for overweight or obesity. Finally, our risk estimates based on a white sample in the United States may not be generalizable to other races or ethnicities. For example, studies have reported that Hispanic and black individuals have demonstrated higher rates of weight gain (30).

Implications

Our estimates of short- and long-term risks for overweight or obesity in people without the condition at a given age can be useful for predicting future risk for over-

weight or obesity in individuals. The complementary estimates of long-term and lifetime risks for overweight or more or obesity that account for baseline prevalence are important to public health. The findings that 9 of 10 young to middle-aged adults are likely to be or to develop overweight or more and that 1 of 2 individuals is likely to have or to develop obesity over 30 years indicate that the burden of overweight or obesity may be underestimated by cross-sectional prevalence data. The lifetime risk for overweight approaches that for high blood pressure (32) and exceeds that described for most other chronic diseases (13, 33–36). These estimates suggest that the future burden of obesity-associated chronic diseases may be substantial.

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Appendix Table. Long-Term Risk for Sustained Obesity: Estimates Conditional on Survival without Obesity up to Baseline Age*

Years from Baseline	Risk for Developing Sustained Obesity (95% CI), %					
	Women			Men		
	Age 30–34 y at Baseline	Age 40–44 y at Baseline	Age 50–54 y at Baseline	Age 30–34 y at Baseline	Age 40–44 y at Baseline	Age 50–54 y at Baseline
10	3.0 (1.6–4.4)	6.5 (4.8–8.1)	6.8 (4.9–8.7)	3.7 (2.0–5.4)	8.2 (6.2–10.2)	7.1 (5.0–9.0)
15	8.4 (6.0–10.7)	12.4 (9.9–14.8)	11.9 (9.1–14.6)	11.2 (8.2–14.1)	16.0 (13.1–18.8)	12.1 (9.1–14.9)
20	16.2 (12.8–19.6)	18.6 (15.1–21.9)	19.4 (14.8–23.6)	21.3 (17.1–25.5)	23.7 (19.8–27.4)	17.2 (12.7–21.2)
25	20.7 (16.6–24.8)	21.5 (17.5–25.3)	24.5 (17.9–30.5)	29.1 (23.9–34.1)	28.9 (24.1–33.3)	26.4 (18.8–32.8)

* Sustained obesity = body mass index ≥ 25 kg/m² at 2 consecutive examinations. Note that only data for 25 y of follow-up are available because of the requirement for attending 2 consecutive examinations. Comparisons with Table 3 should be made only for up to 25 y of follow-up.

APPENDIX

Unadjusted Cumulative Incidence of Obesity

Let $t_1 < t_2 < \dots < t_j < \dots < t_j$ represent the ordered failure times among N participants ($J < N$). Denote by e_j the number of people who fail from the event of interest (obesity in this case) at time t_j and by r_j the number of people at risk at time t_j (their failure or censoring times are $\geq t_j$).

The hazard function, or the conditional probability, of developing obesity at time t_j given survival beyond time t_{j-1} can be calculated as:

$$h_j = \frac{e_j}{r_j}$$

Then the Kaplan–Meier estimate of survival beyond time t (in our case, the probability of not developing obesity) is given by:

$$\hat{S}(t) = \Pr\{T > t\} = \prod_{j=1}^k (1 - h_j) \quad (1)$$

where k is the largest j , such that $t_j < t$ and $r_j = N$.

Equivalently, the Kaplan–Meier estimate of survival can be expressed as $1 -$ cumulative incidence function: $\hat{S}(t) = 1 - \hat{F}(t)$. The cumulative incidence function is defined as a sum of the unconditional probabilities of failure at time t_j . Let us denote them by $\hat{f}(t_j)$. Hence, we can write:

$$\hat{S}(t) = 1 - \hat{F}(t) = 1 - \sum_{j=1}^k \hat{f}(t_j) \quad (2)$$

In the standard Kaplan–Meier approach, the unconditional probability of failure at time t_j , we calculate $\hat{f}(t_j)$ as a product of the hazard function at t_j (the conditional probability of failing at time t_j given survival beyond t_{j-1}) and the probability of surviving beyond time t_{j-1} :

$$\hat{f}(t_j) = h_j \hat{S}(t_{j-1}) \quad (3)$$

This recursive method begins at time t_1 , and we set $\hat{S}(t_0) = \hat{S}(0) = 1$ and the survival analysis performed to obtain $\hat{S}(t_j)$ censors deaths.

The traditional Kaplan–Meier method assumes that the

time scale for failure times is time on follow-up. It can be modified, however, for use with survival age as the time scale. Define:

$$\hat{f}_A = h_A \hat{S}_{A-1} \quad (4)$$

where \hat{S}_{A-1} is the probability of surviving beyond age $A - 1$ and h_A is the hazard function at age A . The cumulative incidence at age A is then given by:

$$\hat{F}_A = \sum_{j=A_{\min}}^A \hat{f}_j = \sum_{j=A_{\min}}^A h_j \hat{S}_{j-1} \quad (5)$$

where A_{\min} is the minimum age at which an event can occur. The survival function is $\hat{S}_A = 1 - \hat{F}_A$.

The remaining lifetime risk for failure from the event of interest is simply the cumulative incidence calculated until the maximum age, that is, \hat{F}_A^{\max} . This method can easily be modified to condition on survival to a particular age, A_S , by setting $\hat{S}_A = 1$ for any $A < A_S$ and by summing from $j = A_S$ instead of from $j = A_{\min}$. In this way, we can calculate the remaining lifetime risk for failure conditional on survival to age A_S . The variance of the estimated cumulative incidence at age A is estimated by the Greenwood formula (37), and 95% CIs can then be constructed.

In our example, the long-term risk for ever developing obesity (until age 70 years) for participants 40 years of age is simply the cumulative incidence ($CI_{70/40}$) of obesity over 30 years:

$$CI_{70/40} = \hat{F}_{70/40} = \sum_j (h_j \hat{S}_{j-1})$$

where h_j is the conditional probability of developing obesity at age j years given survival beyond age $j - 1$ years, \hat{S}_{j-1} is the probability of survival beyond age $j - 1$ years without obesity, and $h_j \hat{S}_{j-1}$ is the unconditional probability of developing obesity at age j years, where the summation is from $j = 40$ to $j = 70$.

Cumulative Incidence of Obesity Adjusted for Mortality

In equation 4, the unconditional probability of failure at age A is the product of the hazard of failure at age A given survival to age $A - 1$. The estimate of the probability of survival to age $A - 1$ is based on an analysis in which deaths are censored and, thus, is an estimate of the probability of survival obesity-free but not necessarily alive. The estimate is not adjusted for the com-

peting risk for death. For this reason, $\hat{F}_{A_{\max}}$ is the “unadjusted” cumulative incidence.

For example, a person who dies before developing obesity cannot develop obesity and should not contribute to the estimate of development of obesity. The potential contribution of censored observations to the probability of failure from the event of interest (in this case, obesity) is distributed among those participants remaining at risk. However, the potential contribution of a participant who has died should be 0. Treating such participants as censored inflates the estimate of cumulative incidence. A more appropriate condition is survival without obesity *and alive*. This probability may be obtained by performing a survival analysis in which deaths are not censored but are counted as competing events of interest along with events of interest (obesity events).

The hazard of failing from either obesity or death at age A can be calculated as c_A/r_A , where c_A is the number of people who develop obesity or die at age A . The estimated survival probability from such an analysis is given by:

$$\hat{U}_A = 1 - \sum_{j=A_{\min}}^A \frac{c_j}{r_j} \cdot \hat{U}_{j-1} \quad (6)$$

Then we modify equation (4) as follows:

$$\hat{f}_A^* = h_A \hat{U}_{A-1} \quad (7)$$

The cumulative incidence adjusted for the competing risk for death is:

$$\hat{F}_A^* = \sum_{j=A_{\min}}^A \hat{f}_j^* = \sum_{j=A_{\min}}^A h_A \hat{U}_{j-1} \quad (8)$$

The variance of the adjusted cumulative incidence can be estimated by using a Taylor series linear expansion (38).

The Practical Incidence Estimators macro provides estimates (and their standard errors) on the basis of unadjusted cumulative incidence and cumulative incidence adjusted for the competing risk for death. The macro uses survival age as the time variable and age at entry into the study as the left-truncation variable.