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# Association of body mass index with all-cause and cause-specific mortality: findings from a prospective cohort study in Mumbai (Bombay), India

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**Background** The association between extremes of relative body weight and mortality has not been well characterized in developing countries. A prospective cohort study was conducted in Mumbai (India) to study the association of relative body weight, as estimated by body mass index [BMI = weight (kg)/height$^2$ (m$^2$)], with mortality.

**Methods** Using the voters' list as the selection frame, 148 173 men and women aged $\geqslant$35 years were recruited during 1991–97 in Mumbai city and were followed-up during 1997–2003.

**Results** During 774 129 person-years of follow-up, 13 261 deaths were observed. After adjusting for the potential confounders, increased mortality was observed in all under-weight categories [relative risk (RR) = 1.94 for BMI < 16.0 kg/m$^2$, 1.38 for BMI 16.0 to <17.0 and 1.24 for BMI 17.0 to <18.5 among women; the corresponding values for men were 2.24, 1.45 and 1.27, respectively] when compared with the rate in the normal weight category (BMI 18.5 to <25.0). Extremely thin (BMI < 16.0 kg/m$^2$) cohort members were at highest risk for death due to tuberculosis (TB) (RR = 7.20 and 14.94 in women and men, respectively), cancer (RR = 1.87 and 2.44, respectively) and respiratory diseases (RR = 3.46 and 4.35, respectively). Subjects with above normal BMI had lower mortality risk than those with normal BMI values. Over-weight (BMI 25.0 to <30.0) women (RR = 0.89) and men (RR = 0.87) were at a lower risk; however, obese (BMI $\geqslant$ 30.0) men <60 years of age had an increased mortality risk (RR = 1.22).

**Conclusion** In Mumbai, under-weight was associated with an increased risk of pre-mature death. Despite the growing concerns regarding the gradual transition toward increasing rates of obesity, under-nutrition remains a major health problem in India. This study suggests the need for public health policies focusing on reducing under-nutrition.

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## Introduction

Studies conducted mainly in Western countries have shown that overweight and obesity are closely associated with increased risk of disability and death due to a variety of diseases, and reduced overall life expectancy.[1,2] Worldwide, obesity is recognized as a serious health problem[3] and increases in childhood over-weight and obesity[4] portend an ominous upsurge in rates of weight-related disease. Although currently not as widespread as it is in the West, alarming increases in obesity are being observed in Asian countries,[5] including India.[6]

While it could reasonably be inferred that rates of chronic disease will follow increases in relative weight in Asian populations as has occurred in the West,[7] data needed to describe the association between obesity and mortality in Asian populations are generally lacking. Additionally, it has been hypothesized that the commonly smaller frame sizes of Asians (relative to the Europeans counterparts) may confound the associations of over-weight and obesity with adverse health outcomes.[8] For this reason, a report co-sponsored by the WHO[5] has proposed a new definition for over-weight and obesity with a focus on the Asia–Pacific region based on body mass index [$BMI = weight\ (kg)/height\ (m^2)$] $\geqslant 23$.

India is the second most populous country in the world that comprises ~17% of the world's population and contributes to 16% of the world's deaths.[9] Nutritional status of the Indian population varies significantly across the regions.[10–12] Certain regions are associated with extremely high rates of childhood under-nutrition (ranging from 20% to 80%), while others have a high prevalence of adult under-nutrition (>50%), and some have both.[10–12]

Earlier, developing countries, including India, had focused scarce public health resources primarily on the high prevalence of under-nutrition.[11] However, these nations are currently facing the double burden of under-nutrition as well as over-nutrition.[6,10–13] Data regarding the nutritional status of adults, as determined by BMI, indicate that 50% of Indian adults suffer from different types of chronic energy deficiency, in that they have a BMI $<18.5\,kg/m^2$. In the same survey, it was observed that the BMI values were similar in men and women; however, there were more over-weight/obese (BMI $\geqslant 25\,kg/m^2$) women (6.6%) than men (3.5%). In certain regions, obesity and consequent diseases are posing an enormous public health problem. Over the last two decades, there has been a clear rightward shift in the distribution, thereby suggesting an improvement in the adults' rates of under-weight over this period.[10] This has been accompanied with a concomitant increase in the obesity rates in certain urban areas.[6,12,13]

Numerous investigations have been conducted in Western countries focusing on the association of BMI (mainly overweight or obese) with mortality. However, there is a dearth of similar such studies from India or other parts of the developing world, where under-weight (BMI $<18.5\,kg/m^2$) continues to pose a major health concern. We examined the association between BMI and all-cause and cause-specific mortality among men and women aged $\geqslant 35$ years in a large cohort study conducted in Mumbai, India.

## Methods

### Recruitment

Mumbai (formerly known as Bombay) is a large and densely populated cosmopolitan city. It is divided into three parts: the main city, the suburbs and extended suburbs. This cohort study was conducted in the main city of Mumbai. A total of 148 173 individuals $\geqslant 35$ years of age were recruited during 1991–97 in the cohort. The voters' lists were used as the sampling frame. These lists provided details including name, age, sex and address of all adults (aged $\geqslant 18$ years) and were grouped into polling stations comprising 1000–1500 voters. We excluded polling stations that comprised upper–middle class and upper class housing complexes. Such complexes were not accessible to us because of security issues (i.e. they were essentially 'gated communities'). The proportion of polling stations that were excluded varied depending on the area. Affluent localities, for example, those containing only skyscraper apartment complexes, were excluded completely; whereas fewer than 10% of polling stations were excluded in other areas.

One-on-one interviews were conducted in the subject's house by trained field investigators using a structured questionnaire that was stored in a hand-held computer (electronic diary). With the exception of very sick or bedridden individuals, the field investigators did not exclude any building, household or individual in the list that was provided to them. The study fulfilled all the criteria related to the ethical protocol formulated by the Indian Council of Medical Research regarding the treatment of human subjects. Details regarding the recruitment procedures have been described earlier.[14]

## Follow-up

An active house-to-house follow-up was conducted ~5–6 years after the initial survey. The field investigators were provided with the list of names and addresses of the cohort members and instructed to revisit each person. A personal interview was conducted if the participant was alive and available. In the event of death of the participant, the date and place of death were recorded with maximal accuracy. Permanent migration from the study area was considered as withdrawal from the study, and the date of migration was noted. The re-interviews were conducted between 1997 and 2003. Detailed results of the follow-up have been described earlier.[15,16]

## Cause of death

Under the uniform system of registration of births and deaths, reporting and registration of births and deaths is compulsory in India. Although the quality of registration varies across different parts of the country, in Mumbai almost all the deaths are registered and certified medically.

In Mumbai, death is reported on a standard death certificate in accordance with the WHO guidelines. The medical section of the death certificate has four lines. The first line is for the major cause initiating the sequence of events leading to death. The second line is for immediate cause of death (stating the disease, injury or complication which caused death, not the mode of dying such as heart failure, asthenia, etc.). The third line is for antecedent cause (morbid condition if any, giving rise to the above cause, stating underlying condition last). The fourth line is for any other condition that contributed to death, but is not related to the causes stated in the first three lines. A properly completed certificate shows only one condition for each line and, in accordance with WHO guidelines, the listed conditions form a causal sequence initiated by the underlying cause. The certificate is generally filled in by the family doctor or by attending physician (when death occurred in hospital). If the circumstances of death are suspicious or violent, the certificate is submitted for completion to the medical examiner and the results are notified with a substantial delay.

Considering the diagnosis of ill-defined causes as a marker for the quality of causes of death certification, in Mumbai Cohort Study the proportion of ill-defined causes among matched deaths were <5% [International Classification of Diseases (ICD) codes R50-69, R95-99].

The cause of death was sought from the municipal corporation death records. For all deaths in individuals' ⩾27 years of age, additional details including demographic information of the decedent and the underlying cause(s) of death were recorded by project personnel. This amounted to >20 000 deaths per year within the study area. The deaths recorded during the follow-up of the cohort were matched with the dataset obtained from the official records obtained from the municipal corporation. Matching was performed using age, sex, name, address and date of expiry. The most important variables for matching were found to be name and address of the deceased. Matching was performed manually in order to obviate any errors due to the difference in the spelling of names between two datasets. For matched deaths, the cause of death was coded according to the ICD-10 criteria. For 1685 randomly selected matched deaths, an independent trained field investigator was sent to the household of the deceased. In all the 1685 revisited deaths, matching was found to be 100% accurate.

## Other data sources

The baseline survey included the following two components: (i) anthropometric measurements that were obtained using a bathroom scale that was calibrated to the nearest kilogram and a measuring tape that was calibrated to the nearest centimeter and (ii) interviewer administration of a structured questionnaire. For this study, data regarding age, sex, education [proxy for socioeconomic status (SES)], religion, mother tongue, height, weight and details of tobacco use were abstracted from the baseline data.

## Statistical analyses

Person-years of follow-up were calculated by using the date of recruitment and the date of end-point ascertainment (defined as the date of expiry, re-interview, migration or censoring). The vital status of the participants who migrated was known at the time of migration (all were alive) but not beyond that date. These participants were included in the analyses, and their data were censored at their date of migration. Additional details regarding the estimation of person-years of follow-up, anthropometric measurements, and information collected from the structured questionnaire have been described earlier.[13–17]

Age-adjusted death rates for men and women were calculated by using the overall 5-year age-specific person-years as weights (i.e. the direct method). Multivariate analysis was performed by using Cox proportional hazards regression modelling.[18] The response variable, death, was fit as a dichotomous variable (yes or no) and the time to event (or censoring) was fit as a continuous variable. BMI categories were defined by using the following two cut-off values: 18.5 and 25.0 $kg/m^2$ for under- and over-weight, respectively. The under-weight category was further sub-divided into the following three groups: extremely thin (BMI <16.0 $kg/m^2$), very thin (BMI 16.0 to <17.0 $kg/m^2$) and thin (BMI 17.0 to <18.5 $kg/m^2$); similarly, the over-weight category was sub-divided into the following two categories: over-weight (BMI 25.0 to <30.0 $kg/m^2$) and obese (BMI ⩾30.0 $kg/m^2$). Details regarding the BMI distribution in the Mumbai cohort have been published earlier.[13,17] Age, education, religion, mother tongue, tobacco use and BMI were fit as independent variables in the final Cox proportional hazards model.[18] Adjusted relative risk estimates (RRs) and 95% confidence intervals (CI) for the association of BMI with mortality, stratified by gender, were estimated.

## Results

Of the total 148 173 (59 515 women and 88 658 men) cohort members, 7265 were not traceable (Table 1); the most common reason for non-traceability was the demolition of their residence (6452 persons) for the purpose of re-development. Among the remaining 140 908 individuals 25 777 subjects were alive but had migrated outside the study area; thus, 115 131 subjects were re-contacted. A total of 13 261 deaths were reported. It was possible to code the cause of death for 9259 deaths. Lack of matching with the municipal death records (1990 deaths) and occurrence of death outside the study area (2012 deaths) were the major reasons for our inability to code the remaining deaths. For 260 subjects, the date of death was found to precede the date of recruitment; hence, data from these subjects were excluded from the analyses. Detailed investigation of a sample of such deaths revealed that the death had occurred very close to the date of recruitment of these subjects. Personal re-interview was conducted for 90 282 individuals; the remaining 11 588 individuals, although assessed to be alive and traceable, were not available despite multiple visits. In the latter group of subjects, the last date of attempted follow-up was regarded as the withdrawal date.

A total of 774 129 person-years of observation were compiled (Table 2). Of the total person-years, 57.8% had normal BMI, 17.8% had below normal BMI and 24.4% had above normal BMI. Women and men with above normal BMI were at a lower risk of death than those with normal BMI values. Higher death rates were observed in both women (Figure 1a) and men (Figure 1b) with below normal BMI when compared with the corresponding rates in women and men with normal BMI across different age groups.

An increased risk of mortality in both extremes (very high and low BMI values; a reverse J-shaped relationship) was observed (Figure 2a and b). Despite adjusting for the possible confounders including tobacco use, there were no substantial variations in the results regarding the main effect of relative weight. Restricting the analyses to never users of tobacco also demonstrated similar results.

Table 3 presents the all-cause and cause-specific death rates. Increased risk of death due to tuberculosis (TB), cancer (men only), non-medical causes (men only) and respiratory system diseases was observed in all of the under-weight categories; and the risk remained high despite excluding deaths that had occurred during the first 2 years of follow-up. The non-medical causes mainly included accidental deaths (≈60%) and deaths due to injuries (≈30%). Overweight men and women were at ≈60 and ≈30% decreased risk of death due TB and respiratory system diseases, respectively; while obese women were at ≈30% increased risk of death due to diseases of the circulatory system.

**Table 1** Distribution of house-to-house follow-up, Mumbai Cohort Study

| | Cohort members | Percentage |
|---|---|---|
| Attempted | 148 173 | 100.0 |
| Status unknown[a] | 7265 | 4.9 |
| Followed-up | 140 908 | 95.1 |
| Migrated | 25 777 | 18.3 |
| Contacted | 115 131 | 81.7 |
| Re-interviewed | 90 282 | 78.4 |
| Died | 13 261 | 11.5 |
| Within study area | 11 249 | 84.8 |
| Matched and coded | 9259 | 82.3 |
| Not available | 11 588 | 10.1 |

[a]The most common reason for a lack of follow-up was demolition of the building where the subject was recorded to be staying.

## Discussion

As the worldwide prevalence of obesity is increasing to epidemic proportions and at an alarming rate,[19,20] concomitant concerns regarding its effect on excess mortality have increased. The association between body weight and all-cause mortality is more controversial—the relationships ranging from linear to J- or U-shaped.[21–26] However, most of these studies have been conducted in Western populations in which only a small proportion of the study participants have low BMI. Our findings are based on the first cohort study from India that has attempted to investigate the association of BMI (mainly low BMI) with all-cause and cause-specific mortality.

Despite the concerns that the epidemiological transition in India and in other low-income countries might result in a double burden of diseases related to both under- and over-nutrition, the findings from this unique and large prospective study suggest that currently under-nutrition remains the main problem in urban India.

### Study strengths and limitations

This cohort study has several characteristics that distinguish it from studies that have been reported

**Table 2** Person-years, number of deaths, death rates, RR and 95% CI by sex for different BMI categories, Mumbai Cohort Study

| BMI ($kg/m^2$) category | Person-years | | Deaths | | Adjusted[a] death rates per 1000 person-years (95% CI) | | Adjusted[b] RR (95% CI) | |
|---|---|---|---|---|---|---|---|---|
| | Women | Men | Women | Men | Women | Men | Women | Men |
| | 330 237 | 443 892 | 3412 | 9589 | 12.61(12.23–12.99) | 19.43(19.02–19.84) | – | – |
| **Below normal (<18.5)** | | | | | | | | |
| All ages | 62 332 | 75 559 | 1092 | 2804 | 18.45(17.39–19.51) | 30.66(29.43–31.89) | 1.52(1.41–1.64) | 1.57(1.50–1.65) |
| Age 35–59 | | | | | | | 1.67(1.45–1.93) | 2.02(1.87–2.18) |
| Age 60 and above | | | | | | | 1.46(1.33–1.60) | 1.35(1.28–1.44) |
| **Extremely thin (<16.0)** | | | | | | | | |
| All ages | 18 164 | 17 764 | 502 | 1079 | 24.32(22.08–26.56) | 48.42(45.26–51.58) | 1.94(1.75–2.15) | 2.24(2.09–2.39) |
| Age 35–59 | | | | | | | 2.65(2.19–3.19) | 3.21(2.88–3.58) |
| Age 60 and above | | | | | | | 1.73(1.53–1.95) | 1.85(1.70–2.01) |
| **Very thin (16.0 to <17.0)** | | | | | | | | |
| All ages | 14 124 | 17 449 | 204 | 609 | 16.12(14.04–18.20) | 28.62(26.15–31.09) | 1.38(1.19–1.60) | 1.45(1.33–1.58) |
| Age 35–59 | | | | | | | 1.56(1.21–2.02) | 1.96(1.72–2.24) |
| Age 60 and above | | | | | | | 1.30(1.09–1.55) | 1.21(1.09–1.35) |
| **Thin (17.0 to <18.5)** | | | | | | | | |
| All ages | 30 044 | 40 345 | 386 | 1116 | 15.25(13.86–16.64) | 23.63(22.15–25.11) | 1.24(1.11–1.39) | 1.27(1.19–1.36) |
| Age 35–59 | | | | | | | 1.14(0.92–1.41) | 1.54(1.39–1.71) |
| Age 60 and above | | | | | | | 1.28(1.12–1.46) | 1.12(1.03–1.22) |
| Normal (18.5 to <25.0) | 170 002 | 277 519 | 1596 | 5340 | 11.61(11.10–12.12) | 17.49(17.00–17.98) | 1.0 | 1.0 |
| **Above normal (⩾25.0)** | | | | | | | | |
| All ages | 97 903 | 90 814 | 724 | 1445 | 9.61(9.00–10.22) | 15.38(14.58–16.18) | 0.91(0.83–0.99) | 0.90(0.85–0.95) |
| Age 35–59 | | | | | | | 1.07(0.93–1.23) | 0.93(0.85–1.02) |
| Age 60 and above | | | | | | | 0.82(0.73–0.92) | 0.88(0.81–0.95) |
| **Overweight (25.0 to <30.0)** | | | | | | | | |
| All ages | 75 068 | 78 939 | 552 | 1226 | 9.51(8.82–10.20) | 15.06(14.21–15.91) | 0.89(0.81–0.98) | 0.87(0.82–0.93) |
| Age 35–59 | | | | | | | 1.03(0.88–1.20) | 0.89(0.80–0.98) |
| Age 60 and above | | | | | | | 0.82(0.72–0.93) | 0.87(0.80–0.94) |
| **Obese (⩾30)** | | | | | | | | |
| All ages | 22 835 | 11 875 | 172 | 219 | 10.04(8.75–11.33) | 17.41(15.06–19.76) | 0.97(0.83–1.14) | 1.05(0.92–1.21) |
| Age 35–59 | | | | | | | 1.20(0.95–1.51) | 1.22(1.01–1.48) |
| Age 60 and above | | | | | | | 0.83(0.66–1.03) | 0.93(0.77–1.13) |

[a]Adjusted (death rates per 1000 person-years) for age, number in the parentheses are 95% CI.
[b]Adjusted for age, education, religion, mother tongue and tobacco use.

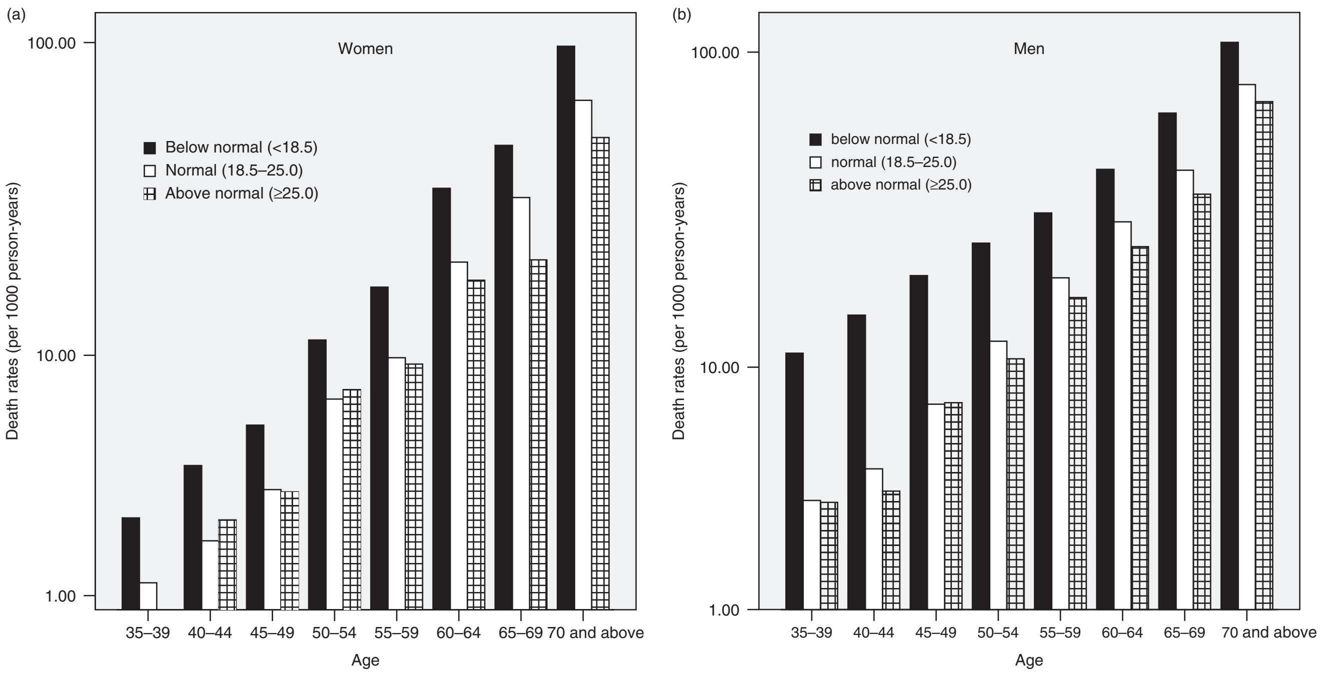


**Figure 1** Age-specific death rates for different BMI categories, Mumbai Cohort Study

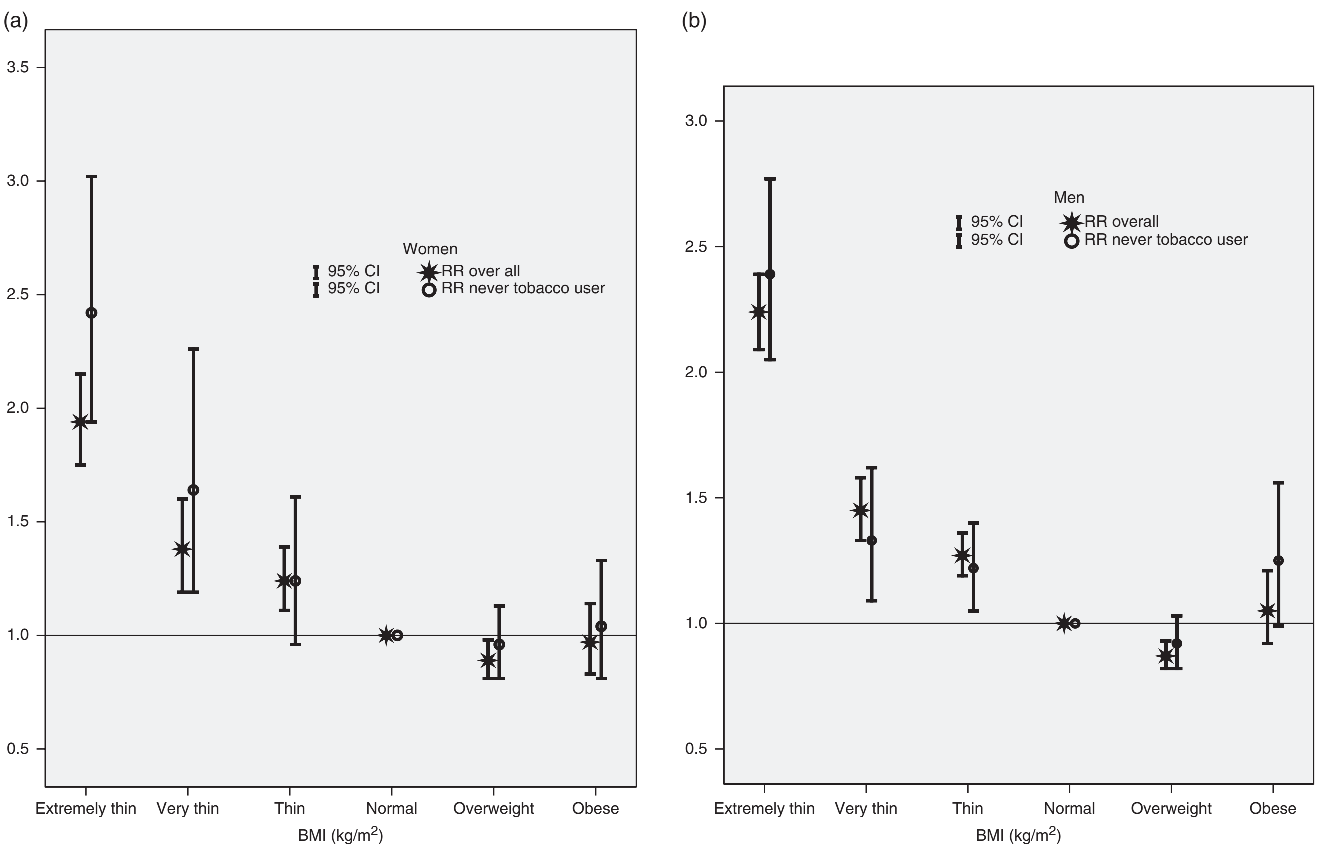


**Figure 2** RR and 95% CI for different BMI categories for all Mumbai Cohort Study members (adjusted for age, education, religion, mother tongue and tobacco habits) vs for never tobacco user (adjusted for age, education, religion, mother tongue)

**Table 3** Adjusted RR for all-cause and cause-specific deaths for different BMI categories by gender, Mumbai Cohort Study

| BMI[a] (kg/m²) category | RR[b] (95% CI) | | RR[b] (95% CI) (excluding deaths occurs during first 2 years of follow-up) | |
|---|---|---|---|---|
| | Women | Men | Women | Men |
| **All deaths** | | | | |
| Extremely thin (<16.0) | 1.94 (1.75, 2.15) | 2.24 (2.09, 2.39) | 1.83 (1.62, 2.06) | 1.92 (1.77, 2.09) |
| Very thin (16.0 to <17.0) | 1.38 (1.19, 1.60) | 1.45 (1.33, 1.58) | 1.36 (1.15, 1.61) | 1.38 (1.25, 1.53) |
| Thin (17.0 to <18.5) | 1.24 (1.11, 1.39) | 1.27 (1.19, 1.36) | 1.15 (1.01, 1.31) | 1.26 (1.16, 1.36) |
| Overweight (25.0 to <30.0) | 0.89 (0.81, 0.98) | 0.87 (0.82, 0.93) | 0.89 (0.80, 0.99) | 0.90 (0.84, 0.97) |
| Obese (⩾30.0) | 0.97 (0.83, 1.14) | 1.05 (0.92, 1.21) | 0.90 (0.75, 1.08) | 1.13 (0.97, 1.32) |
| **Matched and coded deaths** | | | | |
| Extremely thin (<16.0) | 2.05 (1.81, 2.31) | 2.53 (2.34, 2.73) | 1.90 (1.64, 2.19) | 2.18 (1.98, 2.41) |
| Very thin (16.0 to <17.0) | 1.45 (1.22, 1.72) | 1.56 (1.41, 1.72) | 1.40 (1.14, 1.72) | 1.48 (1.31, 1.67) |
| Thin (17.0 to <18.5) | 1.29 (1.13, 1.48) | 1.36 (1.26, 1.47) | 1.17 (1.00, 1.37) | 1.33 (1.22, 1.46) |
| Overweight (25.0 to <30.0) | 0.92 (0.82, 1.03) | 0.86 (0.81, 0.94) | 0.94 (0.82, 1.07) | 0.92 (0.84, 1.00) |
| Obese (⩾30.0) | 1.02 (0.85, 1.22) | 1.07 (0.91, 1.26) | 0.89 (0.71, 1.12) | 1.16 (0.96, 1.40) |
| **TB deaths (A15-19)**[c] | | | | |
| Extremely thin (<16.0) | 7.20 (4.96, 10.44) | 14.94 (12.43, 17.97) | 6.94 (4.43, 10.85) | 12.56 (10.00, 15.78) |
| Very thin (16.0 to <17.0) | 4.09 (2.49, 6.72) | 5.45 (4.25, 6.99) | 4.67 (2.66, 8.18) | 5.15 (3.82, 6.96) |
| Thin (17.0 to <18.5) | 2.04 (1.26, 3.29) | 3.41 (2.73, 4.26) | 2.11 (1.21, 3.70) | 3.01 (2.29, 3.95) |
| Overweight (25.0 to <30.0) | 0.41 (0.21, 0.77) | 0.42 (0.28, 0.63) | 0.46 (0.22, 0.94) | 0.50 (0.32, 0.78) |
| Obese (⩾30.0) | 0.36 (0.11, 1.16) | 0.57 (0.23, 1.37) | 0.50 (0.15, 1.62) | 0.63 (0.23, 1.69) |
| **Cancer deaths (C00-97)** | | | | |
| Extremely thin (<16.0) | 1.87 (1.24, 2.82) | 2.44 (1.85, 3.23) | 1.59 (0.95, 2.64) | 1.54 (1.02, 2.32) |
| Very thin (16.0 to <17.0) | 1.18 (0.65, 2.13) | 1.69 (1.21, 2.36) | 1.21 (0.61, 2.41) | 1.53 (1.01, 2.34) |
| Thin (17.0 to <18.5) | 1.21 (0.79, 1.85) | 1.41 (1.09, 1.84) | 0.95 (0.55, 1.65) | 1.31 (0.94, 1.82) |
| Overweight (25.0 to <30.0) | 0.75 (0.52, 1.07) | 0.84 (0.64, 1.09) | 0.71 (0.47, 1.09) | 0.94 (0.70, 1.27) |
| Obese (⩾30.0) | 0.87 (0.50, 1.51) | 0.95 (0.53, 1.70) | 0.84 (0.43, 1.62) | 0.93 (0.46, 1.88) |
| **Circulatory system deaths (I00-99)** | | | | |
| Extremely thin (<16.0) | 1.19 (0.95, 1.50) | 1.31 (1.13, 1.51) | 1.11 (0.85, 1.46) | 1.07 (0.88, 1.30) |
| Very thin (16.0 to <17.0) | 1.19 (0.89, 1.58) | 0.95 (0.79, 1.13) | 1.07 (0.76, 1.51) | 0.97 (0.79, 1.20) |
| Thin (17.0 to <18.5) | 1.09 (0.88, 1.35) | 0.94 (0.82, 1.06) | 0.89 (0.68, 1.16) | 0.91 (0.78, 1.07) |
| Overweight (25.0 to <30.0) | 1.08 (0.92, 1.28) | 1.00 (0.91, 1.11) | 1.09 (0.91, 1.32) | 1.06 (0.94, 1.19) |
| Obese (⩾30.0) | 1.32 (1.03, 1.69) | 1.22 (0.98, 1.52) | 1.07 (0.78, 1.47) | 1.40 (1.10, 1.78) |
| **Respiratory system deaths (J00-99)** | | | | |
| Extremely thin (<16.0) | 3.46 (2.68, 4.46) | 4.35 (3.62, 5.21) | 3.04 (2.25, 4.11) | 3.52 (2.80, 4.43) |
| Very thin (16.0 to <17.0) | 1.71 (1.14, 2.57) | 2.17 (1.69, 2.77) | 1.71 (1.07, 2.71) | 1.96 (1.45, 2.64) |
| Thin (17.0 to <18.5) | 1.65 (1.21, 2.24) | 1.80 (1.48, 2.20) | 1.72 (1.22, 2.42) | 1.63 (1.29, 2.08) |
| Overweight (25.0 to <30.0) | 0.77 (0.56, 1.06) | 0.63 (0.48, 0.81) | 0.83 (0.58, 1.18) | 0.53 (0.39, 0.74) |
| Obese (⩾30.0) | 0.39 (0.18, 0.84) | 0.39 (0.18, 0.88) | 0.22 (0.07, 0.68) | 0.44 (0.18, 1.06) |
| **Digestive system deaths (K00-93)** | | | | |
| Extremely thin (<16.0) | Very few deaths | 2.41 (1.62, 3.57) | Very few deaths | 1.78 (0.99, 3.17) |
| Very thin (16.0 to <17.0) | | 1.66 (1.05, 2.65) | | 1.50 (0.81, 2.80) |
| Thin (17.0 to <18.5) | | 1.62 (1.16, 2.27) | | 1.87 (1.24, 2.81) |
| Overweight (25.0 to <30.0) | | 0.87 (0.62, 1.21) | | 1.04 (0.70, 1.56) |
| Obese (⩾30.0) | | 1.24 (0.64, 2.44) | | 1.61 (0.75, 3.48) |

(continued)

**Table 3** Continued

| BMI[a] (kg/m²) category | RR[b] (95% CI) | | RR[b] (95% CI) (excluding deaths occurs during first 2 years of follow-up) | |
|---|---|---|---|---|
| | Women | Men | Women | Men |
| **Other medical causes** | | | | |
| Extremely thin (<16.0) | 2.29 (1.76, 2.98) | 1.92 (1.54, 2.38) | 2.09 (1.53, 2.86) | 1.92 (1.48, 2.49) |
| Very thin (16.0 to <17.0) | 1.52 (1.04, 2.22) | 1.61 (1.26, 2.06) | 1.31 (0.83, 2.09) | 1.28 (0.93, 1.77) |
| Thin (17.0 to <18.5) | 1.33 (0.99, 1.78) | 1.46 (1.22, 1.76) | 1.20 (0.84, 1.70) | 1.46 (1.17, 1.82) |
| Overweight (25.0 to <30.0) | 0.92 (0.71, 1.19) | 0.82 (0.68, 0.99) | 0.94 (0.70, 1.26) | 0.89 (0.71, 1.11) |
| Obese (⩾30.0) | 1.07 (0.70, 1.62) | 1.12 (0.75, 1.69) | 1.10 (0.69, 1.76) | 1.08 (0.65, 1.78) |
| **Non-medical causes of deaths (S00-T79, T89-98, V01-Y39, Y85-Y98)** | | | | |
| Extremely thin (<16.0) | 1.17 (0.52, 2.64) | 3.14 (2.11, 4.67) | 1.32 (0.50, 3.45) | 3.01 (1.81, 4.98) |
| Very thin (16.0 to <17.0) | 1.15 (0.41, 3.22) | 1.75 (1.06, 2.92) | 1.36 (0.41, 4.51) | 1.77 (0.94, 3.32) |
| Thin (17.0 to <18.5) | 1.86 (1.01, 3.43) | 1.89 (1.32, 2.69) | 1.85 (0.86, 3.96) | 2.54 (1.70, 3.80) |
| Overweight (25.0 to <30.0) | 0.71 (0.37, 1.36) | 0.85 (0.56, 1.27) | 0.79 (0.37, 1.69) | 0.86 (0.52, 1.41) |
| Obese (⩾30.0) | 0.80 (0.29, 2.26) | 1.44 (0.67, 3.08) | 0.57 (0.14, 2.43) | 1.25 (0.46, 3.42) |

[a]BMI 18.5 to <25.0 was used as a reference categories in respective categories.
[b]Adjusted for age, education, religion, mother tongue and tobacco use.
[c]Coded using ICD-10.

from other industrialized countries. This study used careful mapping to ascertain the target population and an active house-to-house method for enrolling subjects and determining their vital status at the time of follow-up. This method provided accurate information for >95% of the original cohort that was followed-up.

Our study showed high rate of migration. Mumbai, which is the financial capital of India, reported an increase in its overall population from 9.9 million during the 1991 census to 11.9 million during the 2001 census. However, there was a slight decrease in the main city population (from 3.4 million during the 1991 census to 3.3 million during the 2001 census); this was mainly attributed to migration. The major reason for this out-migration is that the industries within the main city closed down, thereby resulting in the migration of industrial labour out of the city. Additionally, a steep increase in real estate prices forced the emigration of poor and lower middle class people to sub-urban areas that were outside the study area. In this regard, however, it is important to note that the migration was not associated with variables important to our analyses including tobacco usage[15,16] and BMI. Among those who migrated, 61% had normal BMI; among those who did not migrate, 57% had normal BMI. The date of migration (available for >99% of the subjects) enabled accurate estimation of person-years of observation for censored data.

We excluded polling stations comprising upper–middle class and upper class housing complexes that were not accessible due to security issues. Similarly, the study excluded homeless persons, such as footpath dwellers, as they are generally excluded from the voters' list. Therefore, the studied cohort may not be truly representative of the Mumbai population.

In our study, BMI categories were based on baseline measurements; however, weight change appears to be an additional important risk factor independent of the initial BMI.[1,27] It would have been preferable to have repeated measures of weight to study the impact of weight changes on mortality[28] but such data were not collected.

In the present study, the categorization of BMI is in accordance with those specified by the recommendations of WHO.[1] Recently, Stevens *et al*.[29] validated the categorization in the WHO report by using a large American cohort of never smokers. BMI values of Asians are lower when compared with those of the Western populations; furthermore, Asians have a higher percentage of body fat for a given BMI.[8,30] Therefore, there are problems with application of standard classification to Asians, and other ethnic groups in a way that is strictly comparable.[5] For Asian populations, the WHO defined over-weight and obesity as BMI values of 23 to <25 and ⩾25 kg/m², respectively. Using the proposed Asian cut-off values did not substantively alter our results (results available from authors).

## Under-nutrition and mortality

Our result demonstrates an inverse relationship between BMI (especially extreme thinness) and mortality; this may be due to inadequate energy intake. Previous findings of an elevated risk of death in the thinnest persons have been attributed to inadequate adjustment for smoking[1,31] and to those who lost weight as a result of an underlying disease.[31] We were able to evaluate the association of these determinants of BMI by adjusting for them with Cox proportional hazards modelling.[18] While it is well established that tobacco use is an independent risk factor for low BMI,[17] these results demonstrated no impact of tobacco use on the relationship (i.e. main effect) between low BMI and mortality (Figure 2a and b). Exclusion of individuals with pre-existing and sub-clinical diseases has not altered the observed association between BMI and mortality in other studies.[27] Although we were not able to exclude individuals with chronic degenerative diseases, the association remained essentially unchanged after excluding the deaths that occurred during the first 2 years of follow-up. Therefore, it appears that inadequate energy intake, possibly associated with poor diet, accounts for the observed relationship between BMI and mortality and that it is a consequence of poverty (with all that this entails).

The relation between cancer mortality and BMI is poorly understood. The J- or U-shaped[32,33] response curve that has been observed in several large datasets indicates that mortality from cancer can account for the largest part of the increased risk of death at both the extremes of relative weight (as estimated by the BMI). Nevertheless, some findings of null[34–36] or even inverted relationships[37] with cancer mortality among those with a low BMI who died early during follow-up[38] support the argument that increased risk might derive from the BMI-lowering effect of pre-existing disease. Our findings were similar to those reported by Song and Sung[39] i.e. disease in individuals with low BMI was unchanged after excluding those with incidence of disease early during follow-up; thereby suggesting that the effect of BMI on death from cancer is not an artefact of measurement timing. However, we acknowledge that our results might be influenced by adiposity-related differences in the natural history or treatment of cancer or by a true biological effect of adiposity on survival. Additionally, it also should be noted that the increased risk of death at low BMI was observed for non-medical causes (primarily accidental deaths) as well. Further probing into the causes of death, the pattern follows expectation in that BMI is associated with chronic diseases of affluence (i.e. those related to circulatory and digestive system dysfunction) in a reverse J-shaped manner. In contrast, BMI is inversely associated with infectious diseases associated with poverty (respiratory system and TB deaths). Cancer deaths follow the poverty gradient; however, this may be related to the under-diagnosis of certain cancers, as we have recently noted.[40]

## Overweight and mortality

While debate regarding the specific BMI range that constitutes over-weight and obesity is likely to continue, there is little doubt that morbid obesity is unhealthy and that it increases one's risk of mortality. However, the results regarding over-weight and mortality are inconsistent. Some studies have observed that over-weight is associated with an increased risk of all-cause mortality,[23–25] while others have reported no excess mortality, particularly in older age groups.[25] Still others have reported a decreased risk of mortality[25,26] when compared with those in the normal weight category. In this study, the risk of death for both over-weight (BMI 25.0 to $<30.0\,kg/m^2$) men ($RR = 0.87$) and women (primarily aged 60 years or more, $RR = 0.82$) was lower than those with normal BMI. They were at ≈60 and ≈30% decreased risk of death due to TB and respiratory system diseases, respectively. While obese men and women were at ≈20% increased risk of death due to diseases of circulatory system, they had ≈60% decreased risk of death due to respiratory system diseases.

In purely biological and physical terms, the etiology of over-weight is similar everywhere, i.e. it is simply due to a chronic imbalance between energy intake and expenditure. The epidemiologic and nutritional transitions observed over many decades (or centuries in the developed countries) were associated with changes in the nature of work, which resulted in a decreased need for physical labour (and reduced energy expenditure) to earn income and drastic reductions in the cost of food (and a concomitant increase in energy intake). Currently, these transitions are being observed in many of the developing countries. The rate and extent of the transitions may vary but the various underlying factors that are responsible for the higher prevalence of obesity seems common. These include factors associated with urbanization and lifestyle factors including lower energy expenditure for physical labour due to mechanization and automation and increases in sedentary leisure-time activities such as watching television.

Mumbai, and indeed most of urban India, is in the midst of a nutritional and epidemiological transition.[12] Thus, the classical relationship that is observed between nutritional status and other socioeconomic variables in Western populations that are in the late stages of nutritional transition is not applicable to the Indian population;[12,41–44] indeed, they may invert dramatically. For example, affluent individuals in India are more likely to be overweight than their less affluent counterparts; in contrast, more affluent individuals are more likely to be thin in the United States.[45] Although SES is important in both contexts, its implications in each may be quite different and the correlates with health may differ similarly. Both sides of the 'energy balance equation' drive differences in relative weight. Besides differences in the characteristics (and cost) of physical labour,[46] the cost of pre-packaged convenience and other 'fast' foods vary dramatically in relation to the more traditional foods (e.g. rice, beans and pulses) between the pre- and post-transition countries. Such pre-packaged and fast food items would be relatively expensive in relation to the minimum wages in India but they would be very inexpensive in the United States.[47] The ability to consume excess calories, with the concomitant result of increases in the prevalence of over-weight and obesity, would depend on the cost per unit calorie relative to income and in comparison with the costs of other commodities. As food prices drop in relative terms, its ushers in a new phase of the nutrition transition[43] and with it, perhaps, a new epidemic of over-weight with adverse health consequence in the developing world. Additionally, the role of factors such as relative weight (here estimated by BMI) may be confounded by economics and social deprivation, phenomena that would invert with affluence[45] and are posited to be important predictors of health as predicted by both Krieger and colleagues[48] and Marmot.[49]

### Conclusions

Moderate to high prevalence of both under- and over-weight can exist within populations in different parts of the world.[50] This is true in our population[13] and is present in other parts of India as well.[51] Low BMI is associated with high mortality in this urban Indian population. These results underline the need for public health interventions that are aimed at reducing the burden of under-nutrition. It should be cautioned that the observed relationships may change as the population transitions toward increased prevalence of over-weight and obesity. Careful monitoring of this population will be necessary in order to alert the policy makers to future public health problems that are currently being observed in association with the obesity epidemic in the West.

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**KEY MESSAGES**

- Despite the concern regarding gradual transition towards increasing rates of overweight and obesity, undernutrition remains the major health problem in India.
- Extremely thin ($BMI < 16.0\,kg/m^2$) women and men were at highest risk of death due to TB, cancer and respiratory diseases.
- Overweight (BMI 25.0–<30.0 $kg/m^2$) women and men were at ≈60% decreased risk for death due to TB and ≈30% for death due to respiratory diseases.
- Obese ($BMI \geqslant 30.0\,kg/m^2$) women and men were at ≈60% decreased risk of death due to respiratory system diseases, but they had ≈20% increased risk of death due to diseases of the circulatory system.
- The association of low BMI and mortality was independent of tobacco use.

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