JOURNAL OF INSURANCE MEDICINE

J Insur Med 2024;51:8–16

MORTALITY

Mortality Risk of Low BMI in Life Insurance Applicants

Steven J. Rigatti, MD, DBIM, DABFM; Robert Stout, PhD

Objectives.—This study seeks to quantify the mortality effect of low levels of body mass index (BMI) on life insurance applicants who, based on their laboratory profile and other information, appear to be suitable for life insurance coverage.
Background.—It has been demonstrated that low BMI is associated with higher mortality risk than normal or near-normal BMI.
Methods.—Data were collected from over 4.7 million life insurance applicants with available BMI tested between 1995 and 2021, and vital status was assessed via the Social Security Death Master File. Cox models treating BMI as continuous and as a categorical variable were constructed, controlling for age, and split by sex after excluding those with laboratory or biometric test results, which were far enough outside the normal range to imply elevated mortality.
Results.—Models treating BMI as a continuous variable and allowing an interaction term for age showed that low BMI was strongly associated with mortality at ages 50 and above in both sexes. In the categorical models, only the lowest category of BMI (below the 1st percentile) in men aged 40-60, the lowest 2 categories (below the 5th percentile) in women aged 40-60, and the lowest 3 categories (below the 10th percentile) in those aged 60-80 years, were significantly associated with elevated mortality. No elevated mortality was detected in those under age 40 with low BMI.
Conclusion.—Based on this study, low BMI is associated with elevated mortality in otherwise healthy applicants, but this association is dependent on age.

Address: Rigatti Risk Analytics LLC, 157 Uconn Ave, Glastonbury, CT 06033; steven.rigatti@crlcorp.com

Correspondent: Steven J. Rigatti, MD.

Author Affiliations: Rigatti – Founder, Rigatti Risk Analytics, LLC, Consultant Medical Director, Clinical Reference Laboratories, Lenexa KS. Stout – Chief Scientific Officer/Laboratory Director, Clinical Reference Laboratories, Lenexa KS.

INTRODUCTION

Body mass index (BMI) is an indirect measure of body composition that is commonly used to determine appropriate weight, overweight, and obesity in adults and children. There are several valid criticisms of BMI, including that it does not consider actual body composition, meaning that trained, muscular individuals may be miscategorized as overweight or obese.[1] However, because of the ease of collection and broad association with disease risk and mortality, BMI is widely used to make both diagnostic and treatment decisions in clinical medicine and as a criterion for mortality risk stratification in life insurance.

The risks associated with being overweight have been exhaustively studied, and include higher risks of diabetes, cancer, heart disease, and all-cause mortality.[2] In many studies of BMI, low levels have also been shown to be associated with the risk of all-cause mortality.[3] This study seeks to quantify the mortality risks associated with low BMI in men and women applying for life insurance at various ages.

METHODS

Clinical Reference Laboratories, Inc. is one of the major providers of lab testing services to the life insurance industry. In this study, data was collected from life insurance applicants between 1995 and 2021. The included subjects had blood and urine testing in addition to home measurement of height, weight, and blood pressure by trained, paramedical examiners during the life insurance application process. Subjects answered simple yes/no questions related to current pregnancy, and personal histories of cancer, heart disease, diabetes, cigarette smoking and non-cigarette tobacco use. To isolate the mortality effect of low BMI, cases were excluded for meeting any of the following criteria: admitted history of heart disease, diabetes, cigarette or non-cigarette tobacco use, a positive blood test for hepatitis B, hepatitis C or HIV, a positive urine test for opiates, cocaine, or cotinine (a nicotine metabolite), hemoglobin A1c above 6.7%, serum creatinine above 1.4 mg/dl, albumin less than 3.7 mg/dl, alkaline phosphatase above 150 U/ml, alanine aminotransferase above 100 U/ml, aspartate aminotransferase above 100 U/ml, gamma-glutamyl transferase above 150 U/ml, total cholesterol above 300 mg/dl, HDL cholesterol below 30 mg/dl, triglycerides above 200 mg/dl, NT-proBNP above 150 mg/dl, average systolic blood pressure above 160 mmHg, average diastolic blood pressure above 100 mmHg, or urine albumin:creatinine ratio above 50 mg albumin per gram creatinine. Women who admitted pregnancy or who were determined by a logistic regression model to have a probability of being pregnant greater than 0.5 were also excluded. These fairly stringent exclusion criteria were applied to ensure that those in the study were likely to qualify for life insurance based on the available information. Since this study is specifically interested in the effect of low BMI, those with a BMI over 27 were removed from the data as were those with a BMI under 15, since they are likely erroneous.

The BMI value was treated as continuous in Cox models controlled for age and split by sex, utilizing restricted cubic splines to allow for non-linear relationships and age interactions to allow for differing relationships between BMI and mortality at different ages. Models were also fitted using categorized BMI. The BMI categories were determined by the 1st, 5th, 10th, 25th and 50th percentiles within the range of BMIs from 15 to 27 for men and women separately. These ranges included the highest value in the range but not the lowest (eg, 18.6-20.5 is 18.6001 to 20.5 exactly). Data were collected from examinations performed between October 31, 1995, and November 22, 2021. Vital status was assessed as of January 29, 2022, from the Social Security Death Master File. Laboratory testing was carried out according to standard protocols. This de-identified data is considered Institutional Review Board (IRB)-exempt, which has been confirmed by independent IRBs in other studies performed on this data set. Analyses were carried out using R version 4.2.3[4] and packages rms, Hmisc, tidyverse, survminer, and all their dependencies.

RESULTS

After all exclusions, the data contained 4,776,967 cases, with an average follow-up time of 8.87 years, during which time 12,076 subjects died. Table 1 shows these values split by sex and by category of BMI.

Figure 1 shows Kaplan-Meier plots for males and females separately by category of BMI. Note that, in both cases, only the lowest BMI category appears to have a higher crude mortality rate than the baseline category. This may be somewhat surprising, but these Kaplan-Meier plots are not adjusted for age.

Cox Models with Continuous BMI

Initial Cox proportional hazard models were fitted, and it was discovered that both age and BMI contained significant non-linear relationships to mortality, though the non-linear effect

Table 1. Baseline Characteristics

Sex	Age	BMI %′ile	BMI	n	d
Females	60–79	$<1^{st}$	15–17.3	2,059	40
		$>1^{st}$ to 5^{th}	17.3–18.7	7,592	95
		$>5^{th}$ to 10^{th}	18.7–19.5	9,847	95
		$>10^{th}$ to 25^{th}	19.5–20.9	29,247	214
		25^{th} to 50^{th}	20.9–22.7	60,877	214
		$>50^{th}$	22.7–27	1,66,801	1,213
	40–59	$<1^{st}$	15–17.3	6,367	24
		$>1^{st}$ to 5^{th}	17.3–18.7	32,549	76
		$>5^{th}$ to 10^{th}	18.7–19.5	49,145	79
		$>10^{th}$ to 25^{th}	19.5–20.9	1,41,736	273
		25^{th} to 50^{th}	20.9–22.7	2,70,149	480
		$>50^{th}$	22.7–27	5,85,953	1,176
	20–39	$<1^{st}$	15–17.3	13,455	14
		$>1^{st}$ to 5^{th}	17.3–18.7	56,679	34
		$>5^{th}$ to 10^{th}	18.7–19.5	71,967	45
		$>10^{th}$ to 25^{th}	19.5–20.9	1,79,815	114
		25^{th} to 50^{th}	20.9–22.7	2,89,189	210
		$>50^{th}$	22.7–27	4,99,694	396
Males	60–79	$<1^{st}$	15–18.6	1,673	42
		$>1^{st}$ to 5^{th}	18.6–20.5	6,851	113
		$>5^{th}$ to 10^{th}	20.5–21.5	10,338	150
		$>10^{th}$ to 25^{th}	21.5–23.0	33,931	404
		25^{th} to 50^{th}	23.0–24.5	19,709	269
		$>50^{th}$	24.5–27	1,60,352	1,650
	40–59	$<1^{st}$	15–18.6	5,415	30
		$>1^{st}$ to 5^{th}	18.6–20.5	25,266	84
		$>5^{th}$ to 10^{th}	20.5–21.5	39,245	119
		$>10^{th}$ to 25^{th}	21.5–23.0	1,28,399	339
		25^{th} to 50^{th}	23.0–24.5	2,51,528	714
		$>50^{th}$	24.5–27	5,54,862	1,623
	20–39	$<1^{st}$	15–18.6	13,925	13
		$>1^{st}$ to 5^{th}	18.6–20.5	54,327	50
		$>5^{th}$ to 10^{th}	20.5–21.5	64,990	57
		$>10^{th}$ to 25^{th}	21.5–23.0	1,69,372	132
		25^{th} to 50^{th}	23.0–24.5	2,62,017	249
		$>50^{th}$	24.5–27	4,53,483	487

BMI = body mass index (kg/m^2); n = number of study subjects; d = number of deaths among study subjects during follow-up.

of BMI was small, possibly due to the data being restricted to those with BMIs under 27. Figure 2 shows the partial effect of BMI on mortality in men and women, centered at age 42, the modal age in the data. Though the curves are of slightly different shape, they do show that low BMI is associated with mortality. However, the question remains as to the shape of this curve at different ages. In a Cox model without interaction term between age and BMI, the shape of the curve will be the same regardless of age.

To overcome this, fully saturated models were fitted using restricted cubic splines with 4 default knots and an interaction term between the BMI and age variables. This

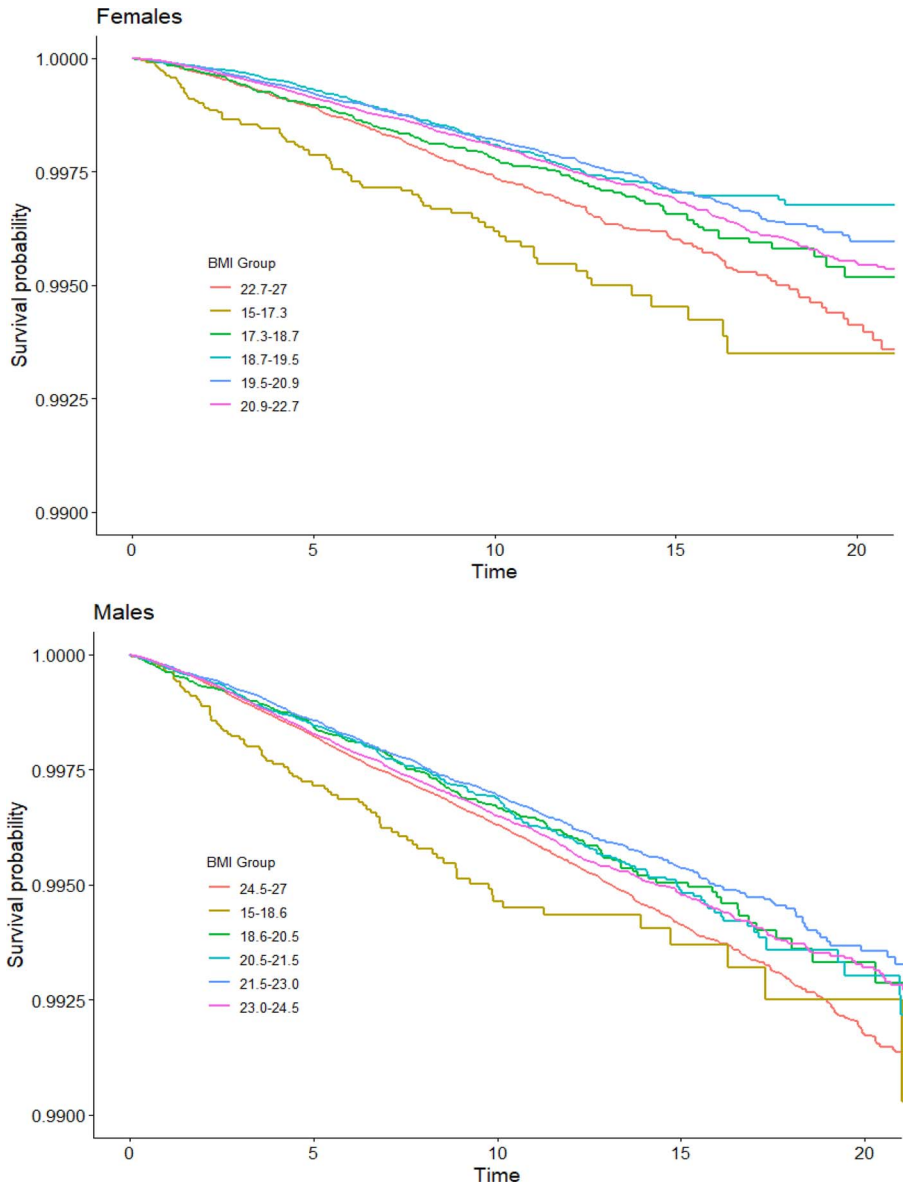

Figure 1. *Kalplan-Meier plots of survival by sex and BMI Group. Time is presented in years. BMI groups are based on percentile thresholds (see Table 1).*

allows for the shape of the BMI-mortality curve to be non-linear and to vary with age. It should be kept in mind, though, that these models will produce results even when there is very little data, or no data, to support the assessment. For instance, there were no subjects over the age of 80 in the data, but the model could generate a prediction for any age. Figure 3 demonstrates the shape of these hazard curves at various ages for men and women. In these plots, the y-axis is transformed to a debits scale, where debits are equal to 100*(HR-1). Debits are calculated by comparing each study subject's predicted HR to that of a subject of the same age and sex with a BMI of 25. In both sexes, the curves for those under age 50 do not reach the 50-debit threshold. For women, the debits associated with low BMI are higher for older individuals, while for men this is not always so. This is somewhat surprising since most impairments carry lower debits at older ages. The mortality of low BMI rises fast enough as BMI declines that it outweighs the higher background mortality at older ages.

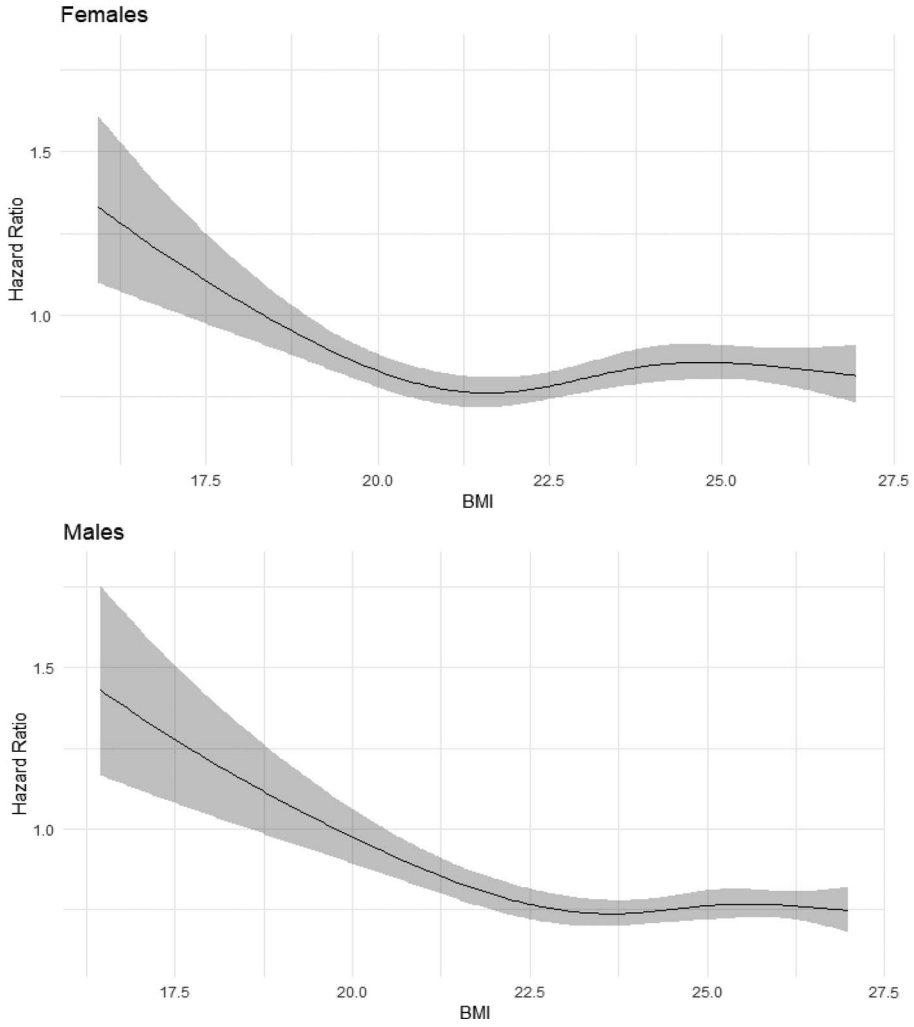

Figure 2. *Partial effects plot of BMI vs the hazard of mortality for men and women in models controlled for age with BMI treated as a continuous variable and modeled with restricted cubic splines with 4 default knots.*

Cox Models with Categorical BMI

Categorical models were fitted using 3 categories of age (<40 years, 40-60 years, and >60 years) and the previously described categories of BMI. No interaction terms were used. The Cox model results are shown in Table 2 and displayed graphically in Figure 4. These models show that for women under age 40, there was no category of BMI associated with a significantly higher mortality than the reference category (BMI of 22.7-27), while for ages 40-60, only the lowest category (15-17.3) had a significant association with mortality (HR of 1.93). For ages over 60, all BMI categories below 19.5 were significantly associated with mortality. For men, the situation was nearly identical, but with higher BMI thresholds. So, for ages 40-60 the lowest BMI category of 15-18.6 was associated with a significant hazard ratio of 1.98, while for men over 60 all 3 categories below 21.5 were associated with significant mortality. In these models, the small numbers of individuals in the lower ranges of BMI are indicated by the width of the error bars.

DISCUSSION

This study demonstrates that, indeed, there is excess mortality risk associated with low BMI, but this association is age-dependent and not clearly demonstrated in the cohort under 40 years of age. In fact, in the fully saturated

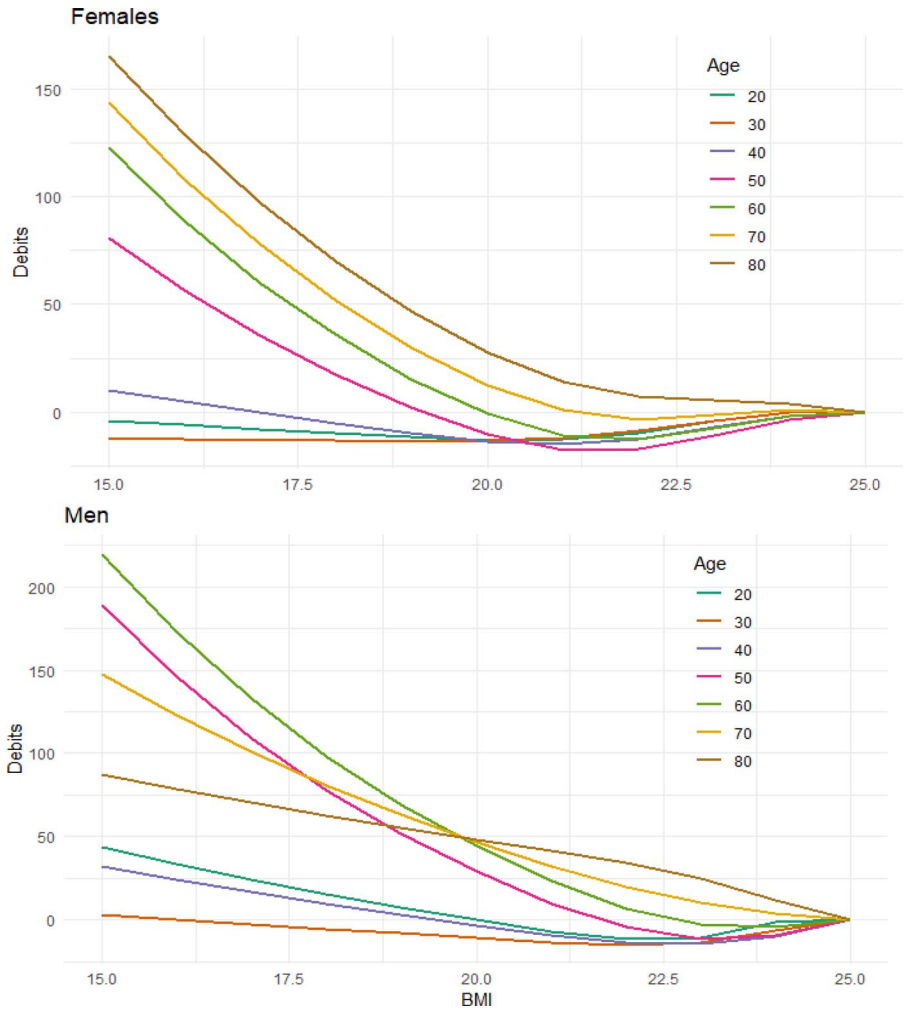

Figure 3. *Debits vs BMI for men and women in saturated models (age and BMI both modeled with restricted cubic splines with 4 default knots and an interaction term between age and BMI). Debits are based on comparison to an individual of the same age and sex with a BMI of 25. Debits = HR*100-100.*

models, the effect shows up around age 50. In men, compared to women, the effect of low BMI begins at a higher threshold. This is an expected finding since men generally have higher BMI than women. This study intentionally restricts the analysis to individuals with BMI less than 27, and to those who, based on their laboratory profiles, do not show reasons for excess risk. This was done to simulate an otherwise low-risk group, and to remove or control for mediating factors such as low albumin and high CEA, which may signal a more ominous cause of low BMI. Also, smokers were not included due to the effect of smoking on both BMI and mortality.

One weakness of this study is the reliance on the Social Security Death Master File for vital status assessment. Though the SSDMF is known to be incomplete,[5] it is unlikely that this incompleteness is dependent on BMI, so a comparison of mortality between BMI groups is likely still relevant. Also, since the mortality effect of low BMI may be longer-term, the study's average follow-up (9 years) may be too short to fully ascertain the effect of BMI. Thirdly, because the laboratory data has only limited health status questions, it is not possible to control for the presence of diseases that may affect both BMI and mortality, such as rheumatic disorders, cancer, and malabsorption syndromes.

Other studies have recognized the association between low BMI and mortality risk. A particularly interesting study by deGonzalez[6] demonstrated a J-shaped mortality curve, similar to

Table 2. Categorical Cox Model Results

Sex	Age	BMI	Estimate	std.error	HR	p.value
Females	>60	15–17.3	0.77	0.19	2.16	<0.001*
		17.3–18.7	0.46	0.19	1.59	<0.001*
		18.7–19.5	0.26	0.12	1.29	0.015*
		19.5–20.9	0.00	0.11	1.00	0.950
		20.9–22.7	0.01	0.06	1.01	0.803
	40–60	15–17.3	0.66	0.28	1.93	0.001*
		17.3–18.7	0.17	0.19	1.19	0.014*
		18.7–19.5	−0.20	0.12	0.82	0.089
		19.5–20.9	−0.02	0.10	0.98	0.733
		20.9–22.7	−0.12	0.06	0.89	0.033*
	<40	15–17.3	0.30	0.38	1.35	0.273
		17.3–18.7	−0.30	0.27	0.74	0.097
		18.7–19.5	−0.27	0.16	0.76	0.084
		19.5–20.9	−0.26	0.14	0.77	0.013*
		20.9–22.7	−0.12	0.08	0.89	0.164
Males	>60	15–18.6	0.75	0.33	2.11	<0.001*
		18.6–20.5	0.38	0.27	1.46	<0.001*
		20.5–21.5	0.28	0.18	1.33	<0.001*
		21.5–23.0	0.09	0.17	1.09	0.115
		23.0–24.5	0.07	0.06	1.07	0.099
	40–60	15–18.6	0.68	0.30	1.98	<0.001*
		18.6–20.5	0.17	0.30	1.18	0.140
		20.5–21.5	0.06	0.28	1.06	0.514
		21.5–23.0	−0.08	0.17	0.92	0.155
		23.0–24.5	−0.03	0.07	0.97	0.506
	<40	15–18.6	0.00	1.00	1.00	0.999
		18.6–20.5	−0.06	0.58	0.94	0.678
		20.5–21.5	−0.14	0.32	0.87	0.324
		21.5–23.0	−0.28	0.24	0.75	0.004*
		23.0–24.5	−0.11	0.11	0.89	0.143

* p-value marked as significant at <0.05 level. All models are controlled for age.

the present study. However, when constraining the follow-up time, it was noted that the hazard ratio for low BMI decreased as the follow-up interval was moved further away from the index measurement. Researchers suggest this may be due to the removal of the effect of prevalent disease, an unmeasured confounder. They also note that the effect is attenuated among the more physically active participants with low BMI. The present study has no information about activity level and, therefore, cannot confirm or deny this effect.

The present study did not demonstrate a significant association of low BMI with mortality risk among men and women below age 50. However, the Global BMI Mortality Collaboration[7] study, which included over 10 million participants and similarly excluded smokers and those with evidence of chronic medical conditions, did demonstrate such an effect. This study excluded the first 5 years of follow-up and was made up of over 230 cohorts from across the globe. Exclusion of early follow-up can be a way to exclude reverse causation (ie, those who have a fatal condition may lose weight before they perish). This was not done in the present study since, in a life insurance context, early deaths are particularly impactful.

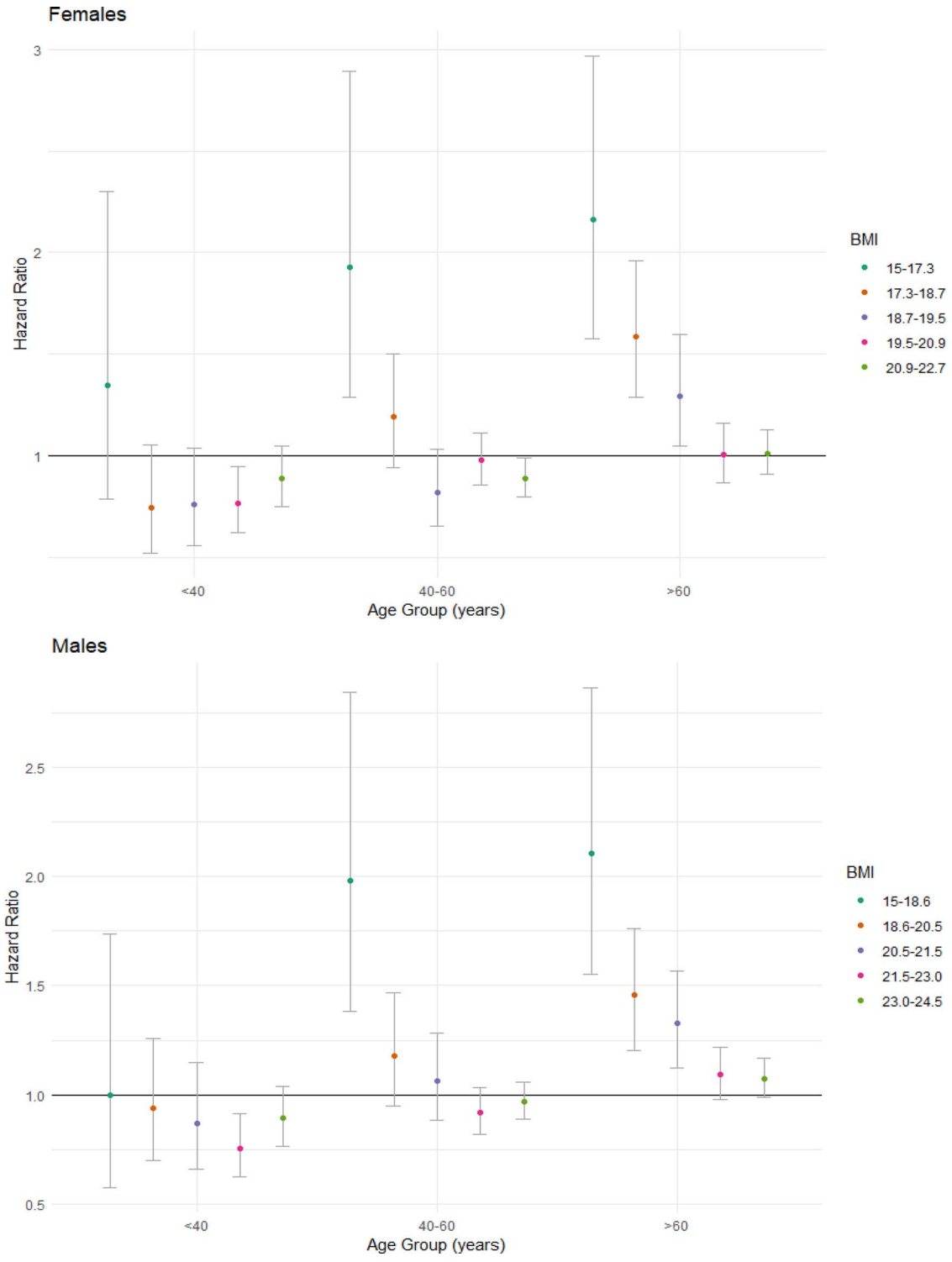

Figure 4. *Hazard ratio vs BMI categories. Each HR is compared to individuals with a BMI above the 50th percentile (22.7-27.0 for women, 24.5-27.0 for men). Error bars reflect the 95% confidence interval.*

A study of residents of Olmstead County, Minnesota, USA[8] controlled extensively for comorbid risk factors and demonstrated that while the mortality risk associated with high levels of BMI was almost completely attenuated by the inclusion of a risk score based on the comorbidities, the effect of low BMI largely remained, except in the lowest risk cohort.

Finally, another study of life insureds was published in the *Journal of Insurance Medicine* by Baldinger,[9] and it showed a similar hazard ratio for underweight individuals as in the present study, though the smaller size of that study meant it could not be subdivided into as many age and sex categories, and it was mostly concerned with the risks of elevated BMI.

CONCLUSION

In a study of life insurance applicants, selected for the absence of significant laboratory abnormalities, low BMI is associated with significant mortality rate increases, but mostly in those over age 40–50 years.

REFERNCES

1. Weir CB, Jan A. *BMI Classification Percentile and Cut Off Points*. In: StatPearls. Treasure Island (FL): StatPearls Publishing; June 26, 2023.
2. Bhaskaran K, Dos-Santos-Silva I, Leon DA, Douglas IJ, Smeeth L. Association of BMI with overall and cause-specific mortality: a population-based cohort study of 3·6 million adults in the UK. *Lancet Diabetes Endocrinol*. 2018;6:944–953. doi:10.1016/S2213-8587(18)30288-2
3. Park HJ, Cho JH, Kim HJ, Park JY, Lee HS, Byun MK. The effect of low body mass index on the development of chronic obstructive pulmonary disease and mortality. *J Intern Med*. 2019;286:573–582. doi:10.1111/joim.12949
4. R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/
5. Ashley T, Cheung L, Wokanovicz R. Accuracy of vital status ascertainment using the Social Security Death Master File in a deceased population. *J Insur Med*. 2012;43:135–144.
6. Berrington de Gonzalez A, Hartge P, Cerhan JR, et al. Body-mass index and mortality among 1.46 million white adults [published correction appears in *N Engl J Med*. 2011;365:869]. *N Engl J Med*. 2010;363:2211–2219. doi:10.1056/NEJMoa1000367
7. Global BMI Mortality Collaboration, Di Angelantonio E, Bhupathiraju ShN, et al. Body-mass index and all-cause mortality: individual-participant-data meta-analysis of 239 prospective studies in four continents. *Lancet*. 2016;388:776–786. doi:10.1016/S0140-6736(16)30175-1
8. Li J, Simon G, Castro MR, Kumar V, Steinbach MS, Caraballo PJ. Association of BMI, comorbidities and all-cause mortality by using a baseline mortality risk model. *PLoS One*. 2021;16:e0253696. doi:10.1371/journal.pone.0253696
9. Baldinger B, Schwarz C, Jaggy C. Cardiovascular risk factors, BMI and mortality in a cohort of Swiss males (1976-2001) with high-sum-assured life insurance cover. *J Insur Med*. 2006;38:44–53.