Obesity and Risk for Death Due to Motor Vehicle Crashes

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Objectives. We examined the role of body mass index (BMI) and other factors in driver deaths within 30 days after motor vehicle crashes.

Methods. We collected data for 22 107 drivers aged 16 years and older who were involved in motor vehicle crashes from the Crashworthiness Data System of the National Automotive Sampling System (1997–2001). We used logistic regression and adjusted for confounding factors to analyze associations between BMI and driver fatality and the associations between BMI and gender, age, seatbelt use, type of collision, airbag deployment, and change in velocity during a crash.

Results. The fatality rate was 0.87% (95% confidence interval [CI]=0.50, 1.24) among men and 0.43% (95% CI=0.31, 0.56) among women involved as drivers in motor vehicle crashes. Risk for death increased significantly at both ends of the BMI continuum among men but not among women ($P<.05$). The association between BMI and male fatality increased significantly with a change in velocity and was modified by the type of collision, but it did not differ by age, seatbelt use, or airbag deployment.

Conclusions. The increased risk for death due to motor vehicle crashes among obese men may have important implications for traffic safety and motor vehicle design. (*Am J Public Health.* 2006;96:734–739. doi:10.2105/AJPH.2004.058156)

Motor vehicle crashes are the leading cause of injury-related death in the United States and accounted for more than 42 000 deaths in 2002.[1,2] Injury pattern and severity of injury due to motor vehicle crashes depend on a complex interaction of biomechanical factors; changes in velocity during a crash, seatbelt use, airbag deployment, and type of collision all play a role.[3] However, the role of body habitus, or body shape, in those interactions is not well understood. The current Federal Motor Vehicle Safety Standards provide protection primarily for the mid-size male (body mass index [BMI]=24.3 kg/m^2),[4] but this standard may apply to fewer people today. During the past 2 decades, more Americans have become obese or extremely obese: a study conducted in 2000 reported that 30.4% of American adults had a BMI of 30 kg/m^2 or greater, and 4.9% had a BMI of 40 kg/m^2 or greater.[5,6]

Mock et al.[7] used a nationally representative sample and found a linear increasing association between BMI and risk for death due to motor vehicle crashes after they adjusted for several confounding factors. The authors speculated that increased comorbidity was the cause. In contrast, Arbabi et al.[3] found a nonlinear association between BMI and motor vehicle crash mortality: normal-weight (BMI <25 kg/m^2) and obese (BMI ≥30 kg/m^2) people had an increased risk for death compared with overweight (BMI=25–29.9 kg/m^2) people. This is possibly because of increased insulating tissue without a significant increase in mass—the cushion effect—among the overweight group.

Women, however, may not be subjected to the same increased risk.[8] Fat deposits and distribution (e.g., subcutaneous fat vs visceral fat and waist vs hip girths) differ between men and women, and body shape affects women's all-cause mortality risk more than it affects men's.[9–12] Yet, the role of obesity, gender, and other risk factors for crash fatality is not known.

We conducted this study to clarify the effects of BMI on driver motor vehicle crash fatality and thereby inform Federal Motor Vehicle Safety Standards and other standards. Accordingly, we assessed whether the association between BMI and motor vehicle crash fatality differed by other risk factors, such as gender, age, seatbelt use, airbag deployment, type of collision, and changes in velocity (km/hr) during the crash. We used a nationally representative sample of police-reported automobile crashes.

METHODS

Database

We used the National Automotive Sampling System's Crashworthiness Data System (NASS CDS), a nationwide crash data collection program sponsored by the US Department of Transportation.[13,14] The NASS CDS is an automated, comprehensive national traffic crash database that includes a wide range of information on accidents, vehicles, and occupants. The NASS CDS data we investigated were a probability sample of all police-reported crashes in the United States that involved passenger cars, light trucks, and vans. Each crash was assigned a weight equal to the inverse of the probability of selection. This type of complex sampling design made it possible to compute weighted estimates that were representative of the entire country. Detailed information about NASS CDS data has been published elsewhere.[14,15]

Study Population

A total of 30 667 subjects, who represented approximately 16 million drivers aged 16 years and older during 1997 to 2001, were eligible for the study. We excluded 8230 subjects for the following reasons: they drove motorcycles or the vehicle type was unknown (n=2154), they were pregnant at the time of crash (n=303), they were missing data on weight or height (n=5713), or they died because of other causes (n=60). In the weighted sample of BMI distribution, we excluded 330 subjects who had BMIs that either were less than 16.7 kg/m^2 or were 45 kg/m^2 or greater—the points that approximately corresponded to the 1st and 99th percentiles, respectively—because extreme BMI values may have been caused by measurement or input errors.

Compared with the 22 107 subjects (13 007 men and 9100 women) included in our analysis, the 8560 excluded subjects (27.9% of eligible subjects) were younger on average (men: 33.3 years vs 35.8 years; women: 33.6 years vs 35.3 years) and had a lower fatality rate (men: 0.33% vs 0.88%; women: 0.25% vs 0.44%).

Variable Definitions

We selected driver, vehicle, and collision variables from the NASS CDS database.[3,7,16] The primary outcome variable was driver fatality, which was defined as death within 30 days after a motor vehicle crash. The risk factor of primary interest was BMI, which was defined as weight in kilograms divided by squared height in meters (kg/m^2). Height and weight were determined from the police accident report or the interviewee or official records (e.g., medical records, including autopsy results).[15]

Covariates

Driver and vehicle variables included the driver's gender, age, alcohol or drug use, seatbelt use, and vehicle age and weight. Alcohol use—either a blood alcohol test result that was greater than zero or a charge of driving while intoxicated or impaired[15]—was coded yes, no, or unknown according to the police accident report. A drug was defined as any chemical substance, natural or synthetic, that can impair the ability to operate a motor vehicle safely.[15] Drug use also was coded as yes, no, or unknown in accordance with the police accident report. Seat belt use was coded as seat belt used, seat belt not used, or unknown according to the police accident report. Vehicle age was defined as the vehicle model year subtracted from the accident year (if the number was negative, the vehicle age was set to zero).

Collision-related variables included air bag deployment, manner and type of collision, road speed limit (km/hr), and change of velocity (km/hr) during the crash. According to the police accident report, air bag status was categorized as air bag deployed, airbag not deployed, or unknown. Manner of collision also was divided into 3 categories: single vehicle, 2 or more vehicles, and unknown. Type of collision was categorized as front-end collision, left-side collision, right-side collision, and other (including back-end, top-side, or undercarriage collision). Road speed limit was the posted speed limit on the roadside. The change in velocity was calculated according to vehicle deformation with a computer program (WinSMASH, National Highway Traffic Safety Administration, Washington, DC) that reconstructs a single 2-dimensional vehicle-to-vehicle impact or a vehicle-to-large-object impact that resembles a barrier collision.[15] Accordingly, change in velocity could not be calculated for certain types of collisions (e.g., rollovers, sideswipes, multiple impacts to the same area, and collisions with animals, pedestrians, or cyclists) or when the data are insufficient.[15]

Statistical Analysis

Driver, vehicle, and collision variables were expressed as the mean or percentage along with the corresponding 95% confidence interval (CI), and they were compared between male and female drivers with an adjusted Wald test.[17] Two models were used in the logistic regression analysis: (1) the *all subjects model* is a model that did not include change in velocity as a covariate and thus included all subjects, and (2) the *change in velocity model* is a model that included change in velocity and thus excluded subjects who did not have change in velocity data.

In the first stage of analysis, we used multiple logistic regression models to estimate the odds ratios (ORs) for driver fatality per unit increase in BMI and adjust for potential confounding factors (all subjects model). BMI together with its quadratic (BMI^2) and cubic (BMI^3) terms were tested in the regression model to determine whether the association with fatality was curvilinear. Several potential confounding factors associated with driver, vehicle, and collision were always included in the regression models: age, manner and type of collision, airbag deployment, seatbelt use, alcohol and drug use, road speed limit, and the vehicle's weight and age. Too few drivers were in the unknown groups of airbag deployment and manner and type of collision to be included in the logistic regression models. Multiple logistic regression models also tested the associations between BMI and gender, age, seatbelt use, airbag deployment, and type of collision to determine whether the association between BMI and fatality differed according to these factors.

In the second stage of analysis, we explored the effects of change in velocity on the association between BMI and fatality. The aforementioned logistic regression models with change in velocity and its quadratic and cubic terms were applied once again to drivers who had available change in velocity data (57%) to determine whether the association between BMI and fatality and the associations between BMI and some driver, vehicle, and collision variables changed after we adjusted for change in velocity (change in velocity model). The association between BMI and change in velocity also was tested. Because change in velocity is thought to be most accurate with front-end collisions, some analyses were restricted to this type of collision.[18]

In the final stage of analysis, we investigated possible differences in driver, vehicle, and collision variables between drivers who did and did not have available change in velocity data. Logistic regression was applied to a binary dependent variable that indicated the presence or absence of change in velocity data; independent variables were driver fatality, driver, vehicle, and collision. To test for fatality differences in BMI among subjects who did and did not have change in velocity data, we also tested the associations between the presence or absence of change in velocity data and driver fatality and its association with BMI (logistic regression models used driver fatality as a dependent variable).

Statistical significance was set at $P<.05$. To produce nationally representative estimates, we used Stata software, version 8.0 (Stata Corp, College Station, Tex) to calculate weighted estimates that adjusted for the complex NASS CDS sampling design.

RESULTS

The fatality rate for motor vehicle crashes that met the inclusion criteria was 0.87% (95% CI=0.50, 1.24) among male drivers and 0.43% (95% CI=0.31, 0.56) among

TABLE 1—Sample and Crash Characteristics, by Gender: 1997–2001

	Male Drivers	Female Drivers
Sample size	13007	9100
Weighted size, millions	6.49	5.06
Driver characteristics, mean (95% CI)		
Age, y	35.9 (34.7, 37.1)	35.2 (34.3, 36.2)
Height, cm	177.9 (177.0, 178.8)	164.3 (164.0, 164.6)*
Weight, kg	81.9 (81.3, 82.5)	66.8 (65.1, 68.4)*
Body mass index,[a] kg/m^2	25.8 (25.6, 26.1)	24.7 (24.2, 25.3)*
Crash characteristics, mean (95% CI)		
Vehicle age,[b] y	7.4 (7.0, 7.8)	6.0 (5.7, 6.4)*
Vehicle weight,[c] kg	1435.4 (1412.4, 1458.3)	1338.9 (1312.4, 1365.3)*
Road speed limit,[c,d] km/hr	67.3 (64.8, 69.7)	66.1 (64.5, 67.8)
Change in velocity,[c] km/hr	21.0 (19.9, 22.1)	19.9 (19.3, 20.6)*
Type of collision, % (95% CI)		
Front end	58.4 (56.3, 60.6)	56.8 (53.1, 60.5)
Left side	14.9 (12.2, 17.5)	15.2 (13.1, 17.2)
Right side	14.8 (13.2, 16.4)	18.4 (17.0, 19.8)*
Other	11.7 (9.6, 13.9)	9.3 (6.6, 12.0)
Unknown	0.2 (0.0, 0.4)	0.3 (0.0, 0.6)
Airbag deployment, % (95% CI)		
Deployed	17.8 (15.7, 19.8)	22.8 (21.2, 24.4)*
Did not deploy	79.7 (77.8, 81.6)	74.9 (72.9, 76.9)*
Unknown	2.6 (1.7, 3.4)	2.3 (1.5, 3.1)
Seat belt use, % (95% CI)		
No	12.0 (7.5, 16.4)	6.1 (3.7, 8.4)*
Yes	81.0 (75.4, 86.7)	87.9 (83.1, 92.6)*
Unknown	7.0 (2.6, 11.4)	6.1 (1.2, 10.9)
Manner of collision, % (95% CI)		
Single vehicle	29.8 (24.8, 34.8)	23.2 (17.9, 28.4)*
2 or more vehicles	68.9 64.0, 73.8)	75.5 (70.2, 80.8)*
Unknown	1.3 (0.7, 2.0)	1.4 (0.4, 2.3)
Alcohol use, % (95% CI)		
Positive	12.6 (9.8, 15.4)	4.9 (2.9, 6.8)*
Negative	75.4 (72.3, 78.5)	83.5 (81.1, 85.9)*
Unknown	12.1 (10.3, 13.9)	11.7 (8.2, 15.2)
Drug use, % (95% CI)		
Positive	2.6 (0.9, 4.2)	1.6 (0.7, 2.5)
Negative	71.6 (62.2, 81.0)	77.4 (70.6, 84.3)*
Unknown	25.8 (16.9, 34.8)	21.0 (13.8, 28.1)*

Note. CI = confidence interval.
[a]Body mass index = weight in kilograms divided by squared height in meters.
[b]Vehicle age = year of accident – year of vehicle model.
[c]Some items had missing values (vehicle weight: men 12 440, women 8756; road speed limit: men 12 668, women 8829; and change in velocity: men 7009, women 5535).
[d]Posted speed limit on the roadside.
*$P < .05$; comparisons between men and women were made with an adjusted Wald test.

female drivers, which is a statistically significant gender difference ($P = .004$). The driver, vehicle, and collision variables are shown in Table 1.

BMI, Gender, and Motor Vehicle Crash Fatality

Logistic regression analysis found significant associations between gender and BMI in the all subjects model and the change in velocity model ($P < .05$). Figure 1 shows the odds ratio for driver fatality among men and women at various BMI values compared with the reference BMI value of 28 kg/m^2 (the lowest point of risk for fatality), which was estimated by the all subjects model with gender-pooled data.

The gender-specific associations between BMI and driver fatality that were adjusted for covariates are shown in Table 2. In both the all subjects and change in velocity models, BMI had a quadratic association with risk for death among men; among women, there was a borderline significance only in the change in velocity model.

Among men, when the associations between BMI and age, airbag deployment, type of collision, or seatbelt use were analyzed, only the association between BMI and type of collision was significant (all subjects model: $P < .05$; change in velocity model: $P < .01$). In both models, front-end and left-side collisions showed a J-shaped association between BMI and fatality, which was not seen for right-side or other collisions. This different association between BMI and fatality was statistically significant between front-end and right-side collisions ($P < .05$), between front-end and other collisions ($P < .01$), and between left-side and other collisions ($P < .05$) in the all subjects model. In the change in velocity model, the significant differences among men were between front-end and right-side collisions ($P < .01$) and between left-side and right-side collisions ($P < .05$). Among women, the only significant association between BMI and the other risk factors in either model was the association between BMI and type of collision in the all subjects model ($P < .01$). However, this association was not significant in the change in velocity model.

BMI and Change in Velocity

The associations between BMI and change in velocity were tested separately for men ($n = 4164$) and women ($n = 3184$) among drivers who were involved in front-end collisions. Significant associations between change in velocity and BMI (i.e., change in velocity × BMI, change in velocity × BMI^2, change in velocity^2 × BMI, and change in velocity^2 × BMI^2) were observed among men ($P < .05$), whereas

TABLE 2—Body Mass Index (BMI) and Driver Fatality, by Gender

	All Subjects Model[a]		Change in Velocity Model[a]	
	β Coefficient (95% CI)	*P*	β Coefficient (95% CI)	*P*
Men				
Sample size	12 122		6905	
Weighted size (millions)	6.06		3.16	
BMI	−0.3995 (−0.6491, −0.1500)	.004	−0.6439 (−0.9810, −0.3068)	.001
BMI^2	0.0070 (0.0030, 0.0111)	.003	0.0113 (0.0062, 0.0164)	<.001
Nadir BMI[b]	28.3 kg/m^2[c]		28.4 kg/m^2[d]	
Women				
Sample size	8623		5493	
Weighted size (millions)	4.81		2.77	
BMI	−0.0035 (−0.2468, 0.2398)	.976	−0.3689 (−0.7397, −0.0019)	.051
BMI^2	0.0003 (−0.0039, 0.0046)	.868	0.0067 (0.0002, 0.0131)	.044
Nadir BMI[b]	. . .	. . .	27.7 kg/m^2[e]	

Note. CI = confidence interval.

[a]Both models also were adjusted for age, seat belt use, airbag deployment, manner and type of collision, alcohol use, drug use, vehicle age and weight, and road speed limit. The change in velocity model was additionally adjusted for change in velocity (km/hr) during the crash. The association between change in velocity and driver fatality was cubic and quadratic among men and women, respectively, in the change in velocity model.

[b]Nadir BMI was calculated as $-\beta_1 / 2\beta_2$ from the coefficients of BMI (β_1) and BMI^2 (β_2) in the all subjects model and the change in velocity model.

[c](95% CI: 26.0, 30.7; $P < .001$)

[d](95% CI: 25.9, 31.0; $P < .001$)

[e](95% CI: 24.3, 31.1; $P < .001$)

BMI and BMI^2 became nonsignificant. Among women, no main factors ($P > .16$) or associations ($P > .90$) with BMI were significant. Figure 2 shows the logarithmic scaled odds ratio for an association between BMI and fatality at different change in velocity levels derived from the effects of BMI and BMI^2. It also shows the associations between BMI and change in velocity among men who were involved in front-end collisions. BMI had an inverted J-shaped association with fatality when change in velocity was low (<15 km/hr), and a J-shaped association when change in velocity was high (e.g., >35 km/hr). The greatest increased risk for fatality was found with the increase in change in velocity at the high end of the BMI continuum. Among women, there was no significant association between BMI and change in velocity with front-end collisions. Age had a strong and increasing association with risk for death due to motor vehicle crashes among both men and women, with and without additionally adjusting for change in velocity (all $P < .001$). The additional age^2 and age^3 terms were further tested in the models, but none had a significant association with fatality among either gender.

Change in Velocity Missing Value

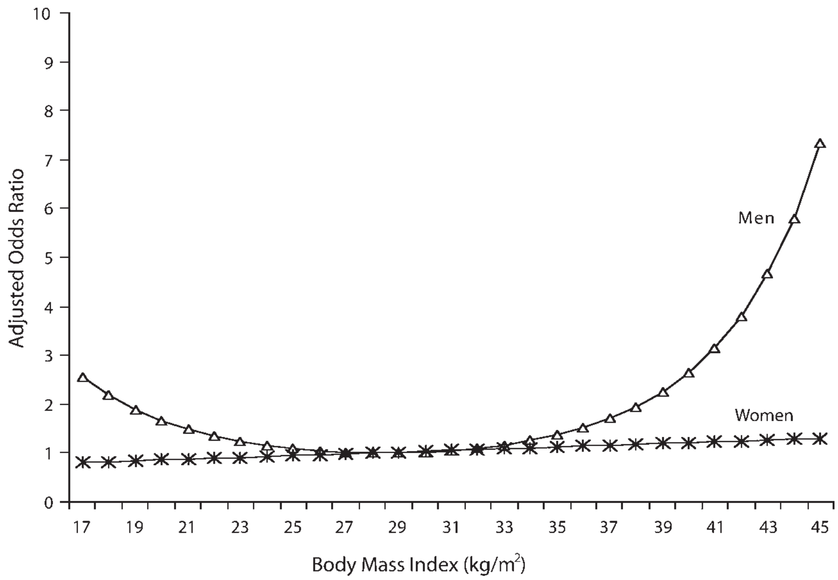
No significant associations for driver fatality were found among the presence or absence of change in velocity data and the variable for drivers (gender, age, BMI, seatbelt use, and alcohol and drug use) or vehicles (age and weight) in the gender-pooled data. However, the presence or absence of change in velocity data had some significant associations with the variable for collisions, such as road speed limit, manner and type of collision, and airbag deployment (all $P < .01$). There was no significant association between BMI and the presence or absence of change in velocity data for driver fatality in the gender-pooled data.

DISCUSSION

This is the first study to test associations between BMI and gender and other important covariates and to show how these factors modified the association between BMI and driver motor vehicle crash fatality. Simultaneously adjusting for potential confounding factors allowed us to assess the association between BMI and fatality over and above other factors. The use of nationally representative NASS CDS data enabled us to describe the associations between BMI and individual motor vehicle crash factors, because the large number of subjects increased the statistical power in analyses. By focusing only on drivers and by using separate analyses for men and women, we eliminated potential differences in gender, causal pathways, and confounding factors between drivers and passengers.

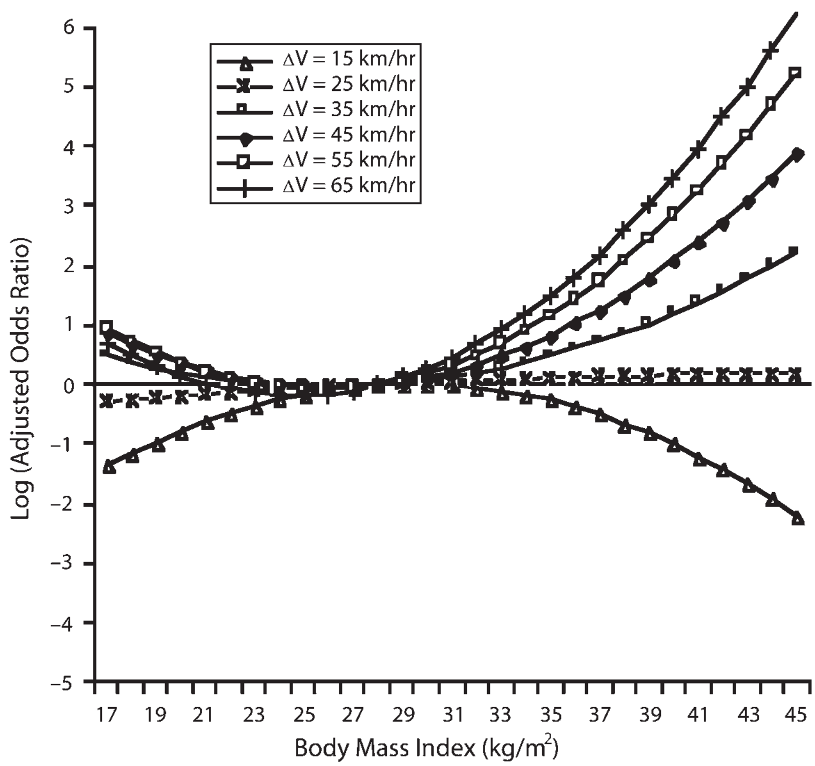
Male drivers who had either a high or low BMI (e.g., BMI > 35 kg/m^2 or < 22 kg/m^2) had a significantly increased risk for death compared with those who had an intermediate BMI, but female drivers did not. Among men, the association between BMI and driver fatality was modified by the type of collision, whereas there was very little difference among either gender in the association with age, airbag deployment, or seatbelt use. The magnitude of the increased risk for fatality at the high end of the BMI continuum among men was determined mainly by the magnitude of the change in velocity.

Men who had higher BMIs were at greatest increased risk for death due to motor vehicle crashes that involved front-end and left-side collisions (approximately 73% of all crashes) but not right-side and other collisions. Statistically, the results for front-end and left-side collisions were not different. However, studies have indicated differences between front-end and left-side collisions in terms of injury and the accuracy of change in velocity calculation.[18,19] A significant association between BMI and change in velocity was detected when the analysis was restricted to men who were involved in front-end collisions (approximately 58% of all crashes) (Figure 2). When the change in velocity was low, the inverted J-shaped association with fatality might have been caused by a cushion effect of increased subcutaneous fat (high BMI) or a smaller momentum effect of the body mass (low BMI).[7,8] Because BMI and weight are highly correlated (R^2=0.78), it was not possible to distinguish whether momentum effects or other obesity factors increased the risk for death when change in velocity was high. We found the lowest risk for crash fatality among men who had a BMI of approximately 28 kg/m^2, which is considered overweight but not obese. This finding supports statistical estimates by



Note. Reference body mass index = 28 kg/m^2.

FIGURE 1—Adjusted odds ratio for motor vehicle crash fatality by drivers' body mass index and gender, all subjects model (n = 20 745).



Note. Reference body mass index = 28 kg/m^2.

FIGURE 2—Logarithmic-scaled adjusted odds ratios of motor vehicle crash fatality by body mass index and change in velocity among male drivers involved in front-end collisions, change in velocity model (n = 4164).

Arbabi et al.[3] that showed a cushion effect of fat among overweight people.

Female drivers in our study did not show significant associations between BMI and change in velocity for fatality. Additionally, women who had elevated BMIs had a significantly lower risk for death than men who had elevated BMIs (Figure 1). This gender differential association remained after we adjusted for height in both the all subjects and change in velocity models of the gender-pooled data (data not shown). The reasons for these gender differences are unknown; however, body shape may be a factor that leads to different injury patterns and severity of injury with a change in velocity. Wang et al.[8] observed an increased subcutaneous fat depth associated with significantly decreased injury severity to the abdominal region among women but not among men.

The increased risk for death due to motor vehicle crashes associated with a high BMI may be caused by some combination of momentum effects, comorbidities of obesity, and emergency and postoperative treatment problems among the obese.[6,7,20–27] Furthermore, obesity imparts anatomical and physiological changes that may either protect or interfere with the body's response to injury.[28] Current vehicle cabin design is in accordance with the Federal Motor Vehicle Safety Standard that used the 50th percentile male Hybrid III Crash Dummy (H3CD, 1.78 m, 77.11 kg in the driver's position, BMI=24.3 kg/m^2).[4] These cabin designs may not be optimal for drivers who have a different body habitus and may contribute to the higher fatality rates at both ends of the BMI continuum.[27,28] Future crash dummy simulations and other studies are needed to account for individual and gender-related variations in body mass and fat distribution in tests of velocity and vehicle design.

Study Limitations

Approximately 28% of the drivers who met the initial inclusion criteria were subsequently excluded from analyses because of missing data on BMI or vehicle type. Missing values might have caused bias in either direction in the associations between BMI and driver fatality, but it is not likely that such exclusion would have had an impact on the results beyond decreasing the precision of statistical estimates.[4] However, bias may have occurred when the regression models were additionally adjusted for change in velocity, which excluded from analyses approximately 43% of drivers who did not have change in velocity data. Our additional analyses indicated that the presence or absence of change in velocity data was associated only with characteristics of a collision, possibly because of difficulties measuring change in velocity.[15] Our analyses were restricted to front-end collisions, which may have somewhat reduced the effects of inaccuracies on change in velocity measurements.[18] Additionally, the results from the all-subjects model were basically similar to those from the change in velocity model, which excluded drivers who did not have change in velocity data. Therefore, the missing values were unlikely to have had any major impact on our findings. Further study is needed to corroborate the hypothesis that the comorbidity associated with obesity is one reason that obesity increases the risk for death due to motor vehicle crashes.

Obese male drivers have a substantially increased risk for death due to motor vehicle crashes, especially at high speeds. Our findings may have important implications for high-risk cohort identification and intervention, e.g., obese men, traffic safety policy, and motor vehicle design.[29,30] Our findings also document another potential major health risk associated with obesity among men. The reasons for the gender difference in BMI and motor vehicle crash fatality are not known and should be studied further. ■

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Contributors

S. Zhu originated the study, analyzed the data, interpreted the findings, and led the writing and revision of the article. P.M. Layde interpreted findings, wrote the article, and provided advice. C.E. Guse interpreted findings. P.W. Laud interpreted findings and assisted with the data analysis. F. Pintar and R. Nirula interpreted findings. S. Hargarten interpreted findings and provided advice.

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Human Participant Protection

This study was approved by the institutional review board of the Medical College of Wisconsin.

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