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Body Mass Index and Mortality in Blunt Trauma: The Right BMI can be Protective

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Background: There are limited studies examining the role of BMI on mortality in the trauma population. The aim of this study was to analyze whether the "obesity paradox" exists in non-elderly patients with blunt trauma.
Methods: A retrospective study was performed on the Trauma Quality Improvement Program (TQIP) database for 2016. All non-elderly patients aged 18–64, with blunt traumatic injuries were identified. A generalized additive model (GAM) was built to assess the association of mortality and BMI adjusted for age, gender, race, and injury severity score (ISS).
Results: 28,475 patients (mean age = 42.5, SD = 14.3) were identified. 20,328 (71.4%) were male. Age ($p < 0.0001$), gender ($p < 0.0001$), and ISS ($p < 0.0001$) had significant associations with mortality. After GAM, BMI showed a significant U-shaped association with mortality (EDF = 3.2, $p = 0.003$). A BMI range of 31.5 ± 0.9 kg/m^2 was associated with the lowest mortality.
Conclusion: High BMI can be a protective factor in mortality within non-elderly patients with blunt trauma. However, underweight or morbid obesity suggest a higher risk of mortality.

1. Introduction

In the United States, it is estimated that by 2030, 1 in 2 adults will suffer from obesity.[1] Recent medical literature has suggested what is now known as the "obesity paradox" – where overall survival appears to be higher in patients that are overweight or obese compared to those who are lean.[2,3] However, this effect has been observed in small sample sizes and single institutional studies.

To date, obesity and body mass index (BMI) have been well-studied in the trauma population at-large, but the relationship with blunt trauma patients remains ill-defined. In some studies, obesity has shown a potential protective effect. Fu et al. found that morbidly obese patients had a lower risk of gastrointestinal injury compared to underweight individuals.[4] Beckmann et al. found that higher BMI was associated with a lower risk of cervical spine injury in female trauma patients.[5] Newell et al. also found that morbid obesity was not associated with increased mortality in trauma patients.[6] At the same time, multiple studies have documented higher in-hospital complications sustained by obese trauma patients such as longer ICU length of stay and sepsis when compared to their non-obese counterparts.[7,8]

Given the various results in current literature, we sought to analyze the national trauma data with a unique statistical analysis. Our hypothesis was that BMI has a non-linear relationship with mortality in the scope of blunt trauma. Specifically, while mortality may increase as BMI increases, the opposite may not hold true. To illustrate this, we utilized the analytical method known as a generalized additive model (GAM). Created by statisticians Trevor Hastie and Robert Tibshirani[9] a GAM assumes that the relationship between the individual predictors and the dependent variable follow a non-linear pattern. Mathematically, the GAM controls for the same biases and variance that a linear or logarithmic regression, but unlike these models, GAM does not assume a priori representation of the data. For example, in a linear regression model, if a relationship does not follow a linear pattern, it is considered not

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significant. In GAM, the parameters of the model allow for the analysis of linear, logarithmic, and non-linear patterns.

2. Methods

A retrospective study was performed on the American College of Surgeons – Trauma Quality Improvement Program (ACS-TQIP) database for the year of 2016. The TQIP database combines demographic and patient outcome data from over 200 Level I and Level II trauma centers nationwide. Elderly patients were defined as age ≥65. All patients, aged 18–64, who had sustained blunt traumatic injuries were identified. These subjects were divided into 6 BMI categories as defined by the World Health Organization (WHO)[10]: 18.4 kg/m^2 and below (underweight), 18.5–24.9 kg/m^2 (normal weight), 25–29.9 kg/m^2 (overweight), 30–34.9 kg/m^2 (Class 1 obesity), 35–39.9 kg/m^2 (Class 2 obesity), 40 kg/m^2 and above (Class 3 obesity). Demographics, mechanism of injury, injury severity score (ISS), hospital length of stay, comorbidities, and mortality were compared among BMI categories using chi-square analysis. Prevalence of different types of falls within each BMI category was also compared through chi-square test. Similarly, prevalence of BMI categories within each type of fall was compared. Statistical analysis was performed using IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, NY, USA). R software was used to build a generalized additive model (GAM) to assess two relationships: the association of mortality (the outcome variable) and BMI, and the association of hospital length of stay (the outcome variable) and BMI. Both models were adjusted for age, gender, race, and injury severity score (ISS). To build these regression models, BMI, the predictor variable, was used as a continuous variable in both models. Significance was set at $p < 0.05$.

3. Results

A total of 28,475 non-elderly patients with blunt trauma were identified in the TQIP database for the year of 2016. The average age of Class 2 and 3 obesity groups was significantly higher compared to patients in the underweight, normal weight and overweight groups (Table 1). The majority of blunt trauma patients were Caucasian males in all BMI categories. Mortality was significantly greater in Class 3 obese patients compared to all other BMI groups. The most common mechanism of injury was falls in underweight, normal weight, and overweight groups. However, trauma sustained by motor vehicle occupants were higher in Class 1, 2, and 3 obese patients.

Patients with Class 3 obesity had the longest mean length of stay in hospital (7.9 days, SD = 6.6) and ICU (5.7 days, SD = 4.9), compared to patients in other BMI categories (Table 1). Injury severity score (ISS) was significantly higher in normal weight, overweight, and Class 1 obese patients versus underweight, Class 2 and Class 3 patients. On further inspection, the standard deviations noted with ICU length of stay and hospital length of stay were most likely a product of the large sample size. This is despite the removal of outliers for those particular variables. However, both hospital length of stay and ICU length of stay increases as one goes from underweight to Class 3 obesity. We do not believe this trend is a product of a large sample size given that the distribution for BMI follows a “normal distribution”.

When reviewing the types of falls, most occurred at ground level across all BMI groups with the largest prevalence in the 18.5–24.9 kg/m^2 category (Tables 2 and 3). In addition, all other fall types were more prevalent in this BMI category when compared to other BMI categories. The only exception was fall from height which was more common in overweight category (25–29.9 kg/m^2) (Table 2). Self-inflicted falls were least likely to occur in underweight and Class 3 patients. Examining Class 1 to Class 3 obese patients, ground level falls were also the most common form of falls, with sports-related and suicide being the least common (Tables 2 and 3). Although not statistically significant, the greatest prevalence of multi-level falls was sustained by individuals in the normal BMI group (Tables 2 and 3). For clarification, sports related falls were falls sustained through skiing, snowboarding, in-line skating or skateboarding. Falls from height included accidents from ladders or scaffolding, natural sites such as cliffs, and other man-made residential structures. Fall from stairs included escalators. Falls from seating included falls from a commode, chair and wheelchair.

After adjusting for age, gender, race, and ISS, the generalized additive model was built to view the association of BMI and mortality. The overall result was a U-shaped curve where mortality was highest in underweight and morbidly obese individuals (Fig. 1). A BMI range of 31.5 ± 0.9 kg/m^2 was associated with the lowest mortality. Age ($p < 0.0001$), gender ($p < 0.0001$), and ISS ($p < 0.0001$) were significant within the generalized additive model ($R^2 = 0.112$, $P < 0.01$). The estimated degree of freedom (EDF) was 3.22 ($p = 0.003$), establishing a significant non-linear relationship between BMI and mortality. The association of BMI and hospital length of stay was also analyzed suing the generalized additive model after controlling for age, gender, race, and ISS. The overall result showed a linear association between BMI ($\beta = 0.058$, $p < 0.0001$) and hospital length of stay; the higher the BMI, the longer the hospital length of stay. Age ($p < 0.0001$) and ISS ($p < 0.0001$) were also significant within the model ($R^2 = 0.121$, $P < 0.01$).

4. Discussion

Using GAM, we studied the relationship of BMI and mortality in the scope of blunt trauma recorded in TQIP database for 2016. Our analysis found that patients with morbid obesity were associated with longer hospital and ICU lengths of stay. Additionally, our analysis revealed that the BMI range of 31.5 ± 0.9 kg/m^2 was associated with the lowest mortality in non-elderly patients with blunt trauma. Underweight and morbidly obese individuals were both associated with a greater risk of mortality. To specify, a linear relationship is graphically represented as a straight diagonal line. As one moves across the x-axis, there is a steady and predictable trend upwards or downwards on the y-axis. In this study, the U-shaped curve denotes a non-linear relationship. While one may expect mortality from blunt trauma to increase as BMI increases, a lower BMI does not necessarily mean lower mortality.

The six categories outlined in this study are accepted by the WHO to stratify obesity.[10] One of the most important limitations that prior studies had in analyzing obesity and blunt trauma was the inconsistency of stratifying BMI. In some studies, a BMI of 31 kg/m^2 or 36 kg/m^2 was used as cut-offs for obesity.[11,12] Lack of a large sample size and single-centered studies were other limitations as well. These issues have been addressed in recent literature. In 2020, Dvorak et al. analyzed 415,807 patients from the national trauma database (NTDB) to examine the role of the obesity paradox in trauma patients. They found that underweight, Class 2 obese, and Class 3 obese trauma patients suffered from increased mortality when compared to normal-weight individuals. Although Class 1 obese patients had no change in mortality, being overweight was found to have a protective effect against mortality.[13] Hoffmann et al. examined four BMI groups: <20.0 kg/m^2 (underweight), 20.0 kg/m^2 –24.9 kg/m^2 (normal weight), 25.0 kg/m^2–29.9 kg/m^2 (overweight), and ≥30 kg/m^2 (obesity) from the Trauma Registry of the German Society for Trauma Surgery (TR-DGU) and found that “underweight” and “obese” individuals had a higher risk of

Table 1
Demographics and hospital outcomes of blunt trauma patients (age 18–64 years).

	BMI Category, kg/m^2						
Demographics, number (%)	<18.5 N = 824	18.5–24.9 N = 10196	25–29.9 N = 9252	30–34.9 N = 4735	35–39.9 N = 1991	≥40 N = 1481	p-value
Age, mean (SD)	41.8 (15.9)	40.3 (14.9)	43.1 (13.8)	44.5 (13.3)	45.3 (13.1)	45.0 (13.1)	0.001
Male	414 (50.2)	7165 (70.3)	7103 (76.8)	3530 (74.6)	1318 (66.2)	798 (53.9)	0.001
Race							
American Indian	5 (0.6)	56 (0.5)	74 (0.8)	34 (0.7)	20 (1.0)	11 (0.7)	0.001
Asian	23 (2.8)	293 (2.9)	186 (2.0)	62 (1.3)	16 (0.8)	19 (1.3)	
African American	111 (13.5)	1215 (11.9)	1023 (11.1)	569 (12.0)	235 (11.8)	218 (14.7)	
Native Hawaiian or Pacific Islander	0 (0)	26 (0.3)	29 (0.3)	9 (0.2)	8 (0.4)	9 (0.6)	
Other race	79 (9.6)	1059 (10.4)	1273 (13.8)	566 (12.0)	220 (11.0)	135 (9.1)	
Caucasian	578 (70.1)	6926 (67.9)	6121 (66.2)	3281 (69.3)	1423 (71.5)	1047 (70.7)	
Mechanism							
Fall	369 (44.8)	3573 (35.0)	2990 (32.3)	1400 (29.6)	621 (31.2)	438 (29.6)	0.001
Machinery	3 (0.4)	65 (0.6)	72 (0.8)	50 (1.1)	15 (0.8)	8 (0.5)	
MVT Motorcyclist	46 (5.6)	811 (8.0)	1031 (11.1)	602 (12.7)	264 (13.3)	143 (9.7)	
MVT Occupant	222 (26.9)	2714 (26.6)	2605 (28.2)	1491 (31.5)	736 (37.0)	628 (42.4)	
MVT Other	6 (0.7)	52 (0.5)	31 (0.3)	29 (0.6)	8 (0.4)	7 (0.5)	
MVT Pedal Cyclist	7 (0.8)	194 (1.9)	112 (1.2)	49 (1.0)	12 (0.6)	2 (0.1)	
MVT Pedestrian	50 (6.1)	692 (6.8)	552 (6.0)	262 (5.5)	76 (3.8)	73 (4.9)	
MVT Unspecified	1 (0.1)	36 (0.4)	47 (0.5)	15 (0.3)	6 (0.3)	5 (0.3)	
Pedal cyclist	11 (1.3)	252 (3.5)	206 (2.2)	56 (1.2)	16 (0.8)	3 (0.2)	
Pedestrian, other	4 (0.5)	81 (0.8)	64 (0.7)	23 (0.5)	7 (0.4)	3 (0.2)	
Struck by, against	61 (7.4)	1026 (10.1)	734 (7.9)	306 (6.5)	85 (4.3)	54 (3.6)	
Transport, other	44 (5.3)	699 (6.9)	808 (8.7)	442 (9.5)	145 (7.3)	117 (7.9)	
Hospital Teaching Status							
Community	241 (29.2)	2829 (27.7)	2413 (26.1)	1270 (26.8)	563 (28.3)	424 (28.6)	0.2
Non-Teaching	120 (14.6)	1436 (14.1)	1316 (14.2)	667 (14.1)	288 (14.5)	202 (13.6)	
University	463 (56.2)	5931 (58.2)	5523 (59.7)	2798 (59.1)	1140 (57.3)	855 (57.7)	
Transfers	239 (29.0)	2766 (27.1)	2477 (26.8)	1382 (29.2)	574 (28.8)	420 (28.2)	0.02
Work Related	21 (2.6)	624 (6.3)	733 (8.1)	353 (7.7)	135 (6.9)	88 (6.1)	0.001
ISS, mean (SD)	15.8 (8.6)	16.6 (8.8)	16.6 (8.8)	16.6 (9.0)	16.2 (8.9)	16.1 (8.7)	0.01
GCS, mean (SD)	12.9 (3.8)	12.8 (3.9)	12.8 (4.0)	12.8 (4.0)	13.3 (3.6)	13.3 (3.7)	0.001
Hospital Length of Stay, mean (SD)	6.1 (5.3)	6.6 (5.7)	6.9 (6.0)	7.1 (6.2)	7.4 (6.1)	7.9 (6.6)	0.001
ICU Length of Stay, mean (SD)	4.5 (4.3)	5.1 (4.5)	5.2 (4.7)	5.5 (4.8)	5.5 (4.8)	5.7 (4.9)	0.001
Mortality	35 (4.2)	360 (3.5)	366 (4.0)	174 (3.7)	70 (3.5)	82 (5.5)	0.007
Comorbidities							
Alcohol use disorder	12 (1.5)	284 (2.8)	254 (2.7)	97 (2.0)	30 (1.5)	18 (1.2)	0.001
Bleeding disorder	4 (0.5)	31 (0.3)	36 (0.4)	22 (0.5)	7 (0.4)	11 (0.7)	
COPD	48 (5.8)	281 (2.8)	193 (2.1)	121 (2.6)	70 (3.5)	91 (6.1)	
Current smoker	127 (15.4)	1640 (16.1)	1302 (14.1)	548 (11.6)	173 (8.7)	121 (8.2)	
Functionally dependent	5 (0.6)	73 (0.7)	41 (0.4)	17 (0.4)	15 (0.8)	10 (0.7)	
Hypertension requiring medication	75 (9.1)	878 (8.6)	1351 (14.6)	961 (20.3)	463 (23.3)	381 (25.7)	
Major psychiatric illness	101 (12.3)	775 (7.6)	622 (6.7)	383 (8.1)	193 (9.7)	170 (11.5)	

(MVT, motor vehicle-traffic; ISS, injury severity score; GCS, Glasgow coma scale; ICU, intensive care unit; COPD, chronic obstructive pulmonary disease).

mortality compared to the normal weight and overweight groups.[14] These findings support our hypothesis that the relationship between BMI and trauma is non-linear.

When examining hospital length of stay and obesity, we found a linear relationship. This finding is supported by numerous other studies which conclude that higher BMI is significantly correlated to longer hospital length of stay as well as increased health care cost compared to non-obese patients.[15–17]

Interestingly, a greater proportion of Class I to Class III obese individuals were noted to be involved in motor vehicle trauma above any other mechanism listed. This pattern was not only seen within BMI groups, but across BMI groups as well – the heavier the patient, the greater likelihood they were of being involved in a motor vehicle accident. Nationwide, vehicle travel and obesity have

Table 2
Prevalence of BMI categories within each type of fall.

		BMI Category, kg/m^2						
Fall Type	Total	<18.5	18.5–24.9	25–29.9	30–34.9	35–39.9	≥40	p-value
Ground level	N = 2709	162 (6.0)	1018 (37.6)	780 (28.8)	377 (13.9)	204 (7.5)	168 (6.2)	0.001
Multi-level	N = 1124	28 (2.5)	410 (36.5)	384 (34.2)	195 (17.3)	67 (6.0)	40 (3.6)	0.07
Sports-related	N = 296	9 (3.0)	157 (53.0)	89 (30.1)	33 (11.1)	6 (2.0)	2 (0.7)	0.001
Suicide	N = 108	1 (0.9)	53 (49.1)	36 (33.3)	14 (13.0)	3 (2.8)	1 (0.9)	0.01
Stairs	N = 1133	37 (3.3)	463 (40.9)	326 (28.8)	184 (16.2)	70 (6.2)	53 (4.7)	0.007
Seating	N = 271	14 (5.2)	84 (31.0)	77 (28.4)	52 (19.2)	20 (7.4)	24 (8.9)	0.006
From height	N = 1117	15 (1.3)	317 (28.4)	452 (40.5)	210 (18.8)	85 (7.6)	38 (3.4)	0.001
From bed	N = 163	12 (7.4)	72 (44.2)	37 (22.7)	20 (12.3)	17 (10.4)	5 (3.1)	0.001

(Sports-related: skiing, snowboarding, in-line skating or skateboarding; From height: ladders,scaffolding, hills, cliffs, man-made residential structures; Stairs: steps, escalators; Seating: chair, commode, wheelchair)

Table 3
Prevalence of different types of fall within each BMI category.

		Fall Type								
BMI, kg/m^2	Total	Ground level	Multi-level	Sports-related	Suicide	Stairs	Seating	From height	From bed	p-value
<18.5	N = 278	162 (58.3%)	28 (10.1)	9 (3.2)	1 (0.4)	37 (13.3)	14 (5.0)	15 (5.4)	12 (4.3)	0.001
18.5–24.9	N = 2574	1018 (39.2)	410 (15.9)	157 (6.1)	53 (2.1)	463 (18.0)	84 (3.3)	317 (12.3)	72 (2.8)	0.001
25–29.9	N = 2181	780 (35.8)	384 (17.6)	89 (4.1)	36 (1.7)	326 (14.9)	77 (3.5)	452 (20.7)	37 (1.7)	0.001
30–34.9	N = 1085	377 (34.7)	195 (18.0)	33 (3.0)	14 (1.3)	184 (17.0)	52 (4.8)	210 (19.4)	20 (1.8)	0.001
35–39.9	N = 472	204 (43.2)	67 (14.2)	6 (1.3)	3 (0.6)	70 (14.8)	20 (4.2)	85 (18.0)	17 (3.6)	0.003
≥40	N = 331	168 (50.8)	40 (12.1)	2 (0.6)	1 (0.3)	53 (16.0)	24 (7.3)	38 (11.5)	5 (1.5)	0.001

EDF = 3.22 (p = 0.003) indicates a significant, non-linear association between BMI and mortality after adjusting for age, gender, race and ISS.
(Sports-related: skiing, snowboarding, in-line skating or skateboarding; From height: ladders ,scaffolding, hills, cliffs, man-made residential structures; Stairs: steps, escalators; Seating: chair, commode, wheelchair)

both surged in the United States, with a high correlation between miles driven and BMI.[18] Other studies have shown that obese individuals are at higher risk of mortality and serious upper body injury during motor vehicle accidents.[19,20]

Historically, studies examining the effect of BMI on trauma outcomes have had conflicting results. The general belief was that BMI exhibited a linear or logistic relationship with mortality – the more obese, the higher the mortality. Although this is partly the answer, in reality, the relationship was non-linear. We used the generalized additive model because it does not assume a priori representation of the data.[9] Linear regression models take continuous variables to plot a linear relationship and assumes a priori linearity. That is one of the largest drawbacks of this regression model. Non-linear relationships (data that does not follow a linear or logistic pattern) can be missed. A generalized additive model (GAM) is seen as a way to counter these effects.[21] At the same time, this statistical approach is not novel. Zajacova et al. published a study using GAM, analyzing the relationship between BMI and cause of death from multiple medical conditions ranging from cardiovascular demise, cancer, and diabetes.[22] In regards to cardiovascular mortality, their study showed a V-shaped curve similar to ours.

Unfortunately, mechanistic explanations for the obesity paradox seen in various medical and surgical conditions are not well established. When reviewing the "protective" effects of obesity in the cardiology literature, one study found that lean patients had worse underlying non-cardiovascular diseases compared to their obese counterparts.[23] Another study examined the quality of health at baseline using the 36-item short-form health survey (SF-36) and found no difference between obese and non-obese patients.[24] When examining the comorbidities of trauma patients in this study, we found that patients who were overweight or Class 1 obese had lower incidences of chronic obstructive pulmonary

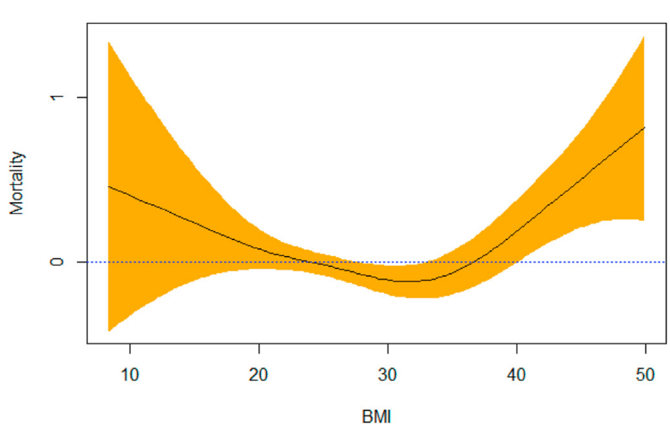

Fig. 1. Association of mortality and BMI in blunt trauma.

disease (COPD) and major psychiatric illnesses. More importantly, fewer patients were functionally dependent in the overweight and Class 1 obesity group (Table 1). Functional dependent status prior to trauma or major surgery has been shown to be an independent risk factor for mortality.[25,26] The hypothesis that different comorbidity profiles between obese and non-obese patients may contribute to the obesity paradox is worth exploring.

One weakness of this study was the retrospective nature of the data. Information provided by databases are inherently limited and do not appropriately highlight the complex relationship between obesity and blunt trauma. In addition, multiple studies have shown that BMI may not be the best indicator of obesity. In terms of predicting metabolic syndrome or cardiovascular health, adjuncts such as waist-to-hip ratio (WHR) are considered a more accurate measure.[27–29] One study by Joseph et al. found that WHR, more so than BMI, was an independent predictor of mortality and hospital complications in the trauma population.[30] Future studies may wish to examine WHR in blunt trauma patients prospectively.

5. Conclusion

Although the relationship between BMI and mortality in blunt trauma patients has been well-documented, this is the first study to utilize a generalized additive model to provide a unique trend. We found that in non-elderly patients with blunt trauma, BMI of 31.5 ± 0.9 kg/m^2 had the lowest risk of mortality.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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