EFFECTS OF BODY MASS INDEX ON MOTOR VEHICLE CRASH INJURIES IN PEDIATRIC CASES

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

AIS	Abbreviated Injury Scale
BIV	Biologically Implausible Value
BMI	Body Mass Index
CDC	Centers for Disease Control and Prevention
CI	Confidence Interval
CIREN	Crash Injury Research and Engineering Network
IRB	Institutional Review Board
MVC	Motor Vehicle Crash
NASS CDS	National Automotive Sampling Survey Crashworthiness Data System
NHTSA	National Highway Traffic Safety Administration
OR	Odds Ratio
PDOF	Principal Direction of Force
REF	Reference group
WHO	World Health Organization

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ABSTRACT

Background: Recent increases in childhood obesity have important implications for motor vehicle safety, particularly given that over 1.5 million children in the United States are involved in motor vehicle crashes each year. Among the pediatric population, motor vehicle crashes represent the leading cause of death and disability.

Methods: A secondary analysis was conducted on a cohort of children aged 2-14 years involved in crashes nationwide from 1996-2007 with data from the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS), provided by the National Highway Traffic Safety Administration. An Abbreviated Injury Scale (AIS) score of 3 or more, including serious, severe, critical or maximum injuries were compared to those with an AIS score of 2 or less, indicating moderate, minor or no injury. Body Mass Index (BMI) for age consisted of 5 categories: underweight, normal, overweight, obese and severely obese, with normal serving as a reference. Multivariate logistic regression was used to test the potential effect of BMI-for-age on the risk of serious injury (AIS ≥3).

Results: The injury distribution included 98.8% of children who suffered injuries of AIS ≤2 as compared to 1.2% of children who suffered injuries of AIS ≥3. Of those children who were seriously injured, a total of 7.2% were considered underweight, 48.0% were considered normal weight, 16.8% were considered overweight, 17.1% were considered obese and 10.9% were considered severely obese. Children classified as overweight were found to be at a significantly greater risk of serious injuries and death, as compared to normal weight children (OR=3.89, 95% CI: 1.55-9.76). However, it is important to note that this association is not robust to all specifications, including an alternate model that provides a larger sample size but excludes variables related to crash severity, which appeared to negatively confound the association between BMI-for-age and serious injury and death. Regardless of model specification, proper restraint of children significantly reduced the risk of serious injury and death, by 77 to 88 percent.

Conclusions: Based on the results of the multivariate logistic regression, we failed to reject the null hypothesis that the risk of serious injury including death (AIS ≥ 3) is the same for obese children relative to children with normal BMI-for-age. However, risk of serious injury and death may be elevated in overweight children.

BACKGROUND

Childhood obesity is considered one of the most serious public health challenges of the 21st century.[1] As a result, leading health organizations in the United States have identified the prevention of childhood obesity as a top priority.[2] Currently, 31.9% of children and adolescents are considered to be overweight, while 16.3% are considered to be obese.[3] Obese children are more likely to have risk factors associated with cardiovascular disease and are more likely to become obese as adults.[4] Obesity has been found to lead to numerous health complications and to contribute to an increased risk of morbidity and mortality.[5] In addition to increased risk of chronic disease, obesity in children has been associated with increased risk of injury.[6 7]

Increases in obesity have important implications for motor vehicle safety. Over 1.5 million children are involved in motor vehicle crashes (MVCs) each year. Among the pediatric population, MVCs represent the leading cause of death and disability. Motor vehicle crashes account for 23% of injury deaths among infants and 30% among pre-school aged children.[8] It is possible that the greater mortality rates among toddlers may be due to an increased amount of time spent in motor vehicles. Despite the fact that the use of seatbelts has been shown to decrease mortality and reduce the incidence of serious injuries in children, suboptimal restraint among children, particularly among those 4 to 8 years of age remains common.[9] Further, the shift in the distribution towards larger body size in BMI-for-age in children may reduce the protective capacity of child safety seats. Trifiletti et al. (2006) determined that a substantial number of children weigh more than the upper weight limit for most currently available child safety seats.[10]

There is limited research on the association of BMI between fatal and non-fatal injuries among children resulting from motor vehicle crashes. In a recent cross-sectional study of 9-15 year olds involved in motor vehicle crashes, Pollack and colleagues (2008) demonstrated no significant increase in overall injury risk as BMI increased.[11] However, the authors discovered that the risk of sustaining an injury to the extremities, Abbreviated Injury Severity Score (AIS) >2, was over 2.5 times as great for overweight and obese children as compared to normal weight children (OR=2.64, 95% CI: 1.64-4.77 and OR=2.54, 95% CI: 1.15-5.59, respectively). The researchers suggest that the increased risk of extremity injuries is due to a combination of physiology and biomechanical factors. A potential limitation of this study is the fact that the children's weight and height measurements, which were used to calculate their BMI-for-age, were reported by their parents. Even so, a non-differential error in the parents' report of height and weight would be expected to result in bias toward the null. Using the CIREN database, Zaveri et al. (2009) examined motor vehicle collisions for overweight subjects aged 2-17 years old and found no significant relationship between pediatric injury severity and being overweight.[12]

Although there is limited research on children, several studies of adults have examined the role of BMI in relation to severe injuries and mortality from motor vehicle crashes. Zhu et al. (2009) found that obese men have a much higher risk of upper body injury during motor vehicle crashes. Interestingly, a U-shaped relationship was found between body mass index serious injury to the abdominal area for both men and women.[13] A large cohort study in New Zealand reported a U-shaped association between BMI and the risk of fatal or serious non-fatal driver injury with higher injury risk observed for underweight and overweight/obese adults.[14] Using the National Automotive Sampling Survey (NASS) Crashworthiness Data System (CDS), Mock et al. (2002) present presumptive evidence that increased body weight and increased BMI result in increased injury severity (ISS ≥ 9), an association which was attributed to increased comorbidity.[15] Interestingly, a recent study by Ryb and Dishchinger (2008) found that although obese and overweight patients experience higher unadjusted and adjusted mortality rates, overweight patients, but not obese patients, experienced more severe injuries (OR = 2.44, $p = 0.009$), after adjusting for several important factors.[16]

Among adults, research suggests that obesity may influence the risk of mortality associated with MVCs for both passengers and drivers. Obese drivers have been found to experience both higher adjusted and unadjusted mortality rates. Christmas et al. (2007) demonstrated a fourfold increase in mortality among morbid obese patients compared with those with a normal BMI.[17] Mock et al. (2002) found a linear association between increased body weight and increased mortality in MVCs, which might have been in part due to increased severity of injury among the more obese occupants.[18] Several investigations suggest that there are gender differences between BMI and MVC injuries and mortality among adults. Female drivers have been found to have the highest relative risk of serious injury when obese as compared to women with normal BMI.[19] In contrast, Zhu et al. (2006) in their analysis of NASS CDS data found an increased risk of death due to MVCs among obese men but not women.[20] The observed 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. In a matched-pair analysis of front-seat motor vehicle occupants, Viano and colleagues

(2008) demonstrated that obese drivers were have a 17% higher risk of serious injury than normal BMI drivers and a 97% higher risk of fatality.[21] This effect was greatest among obese female drivers and young drivers.

In regards to adult mortality from MVCs, Arbabi et al. (2003) found a non-linear association between normal and obese occupants as compared with occupants who were overweight.[22] The authors hypothesized that normal-weight BMI and obese people had an increased risk for death compared with overweight people due to increased insulating tissue without a significant increase in mass, known as the "cushion effect". Similarly, findings by Wang et al. (2003) suggest increased subcutaneous fat may be protective against injuries in motor vehicle crashes by cushioning the abdominal region.[23] However, the protective effect, which observed with abdominal injuries may not be applicable to other types of trauma in MVCs. Several investigations indicate that obese adults sustain a different injury pattern compared to those of normal weight, including femoral fractures,[24] diaphragmatic injury in patients involved in near-side MVCs,[25] and asphyxia death.[26-28] Therefore, it is reasonable to posit that similar modifications of injury risk may be present in children involved in motor vehicle crashes.

The lack of specific research on children indicates a significant gap in the literature. The present analysis uses the NASS CDS to investigate the hypothesis that BMI in children, just as observed in adults, modifies the risk of serious injury and death from vehicular trauma. We test the hypothesis that children who are overweight and obese are at increased risk of serious injury in motor vehicle crashes.

SIGNIFICANCE

Given the growing number of children and adolescents in the United States who are overweight and obese, it is an important time to improve our understanding of the role of BMI on injury outcomes. Expanding the limited existing research on pediatric injury and BMI-for-age may elucidate necessary improvements to motor vehicle safety systems and injury prevention strategies and by extension contribute to a significant decrease in childhood injury and mortality related to motor vehicle crashes.

METHODS

Data Source

The sample was selected from the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) database, provided by the National Highway Traffic Safety Administration. The NASS CDS is a probability-sampled, population-based, nationally representative cohort of persons involved in motor vehicle crashes. In order to ensure national generalizability of the data, the data in the NASS CDS are collected using a 3-stage sampling process of motor vehicle crashes from 24 sites throughout the United States.[29] Also, in an effort to generate unbiased estimates and to ensure accurate calculations of variance, analyses of NASS CDS data employ clusters, strata and probability weights.

Subject Selection

The sample used in this analysis was restricted to child occupants 2 to 14 years of age who were injured in motor vehicle crashes during the years of 1995 through 2006. Previous research supports the restriction of children to 14 years old or younger in an effort to assemble a more homogenous group.[30] Teenagers (15-18 years old), adults (18 years of age or older), and drivers (of all ages) were excluded. Pregnant girls, of whom there was only one under the age of 14, were also excluded from analysis. In an effort to employ consistent weight metrics for our primary independent variable, children aged 1 year or younger were excluded because the CDC does not provide a BMI-for-age growth chart, but rather a weight-for-age growth chart for children under the age of two.

The World Health Organization (WHO) has defined limits for acceptable data related to BMI-for-age. For example, data can include a flexible exclusion range that reflects 4 z-score units from the observed mean z-score, with a maximum height-for-age z-score of +3.0. [31] Based on their recommendations for outlier cutoffs, we identified biologically implausible values (BIV) using z-score data provided by the CDC, as well as specific commands in Stata. Overall, 117 cases were deemed to be outliers based on this criterion and thus removed from the analysis.

Study Measures

Primary Independent Variable

For the purposes of this analysis, the primary independent variable is Body Mass Index (BMI) for age, classified as an ordinal variable with five categories: “underweight”, “overweight”, “obese” and “severely obese”, with normal BMI-for-age serving as the reference group. The fifth BMI-for-age category, “severely obese”, is examined based on the recommendations of the American Medical Association Expert Committee (2007), as an important area for additional study and represents the 99th percentile of BMI-for-age[32]. According to the Centers for Disease Control and Prevention (CDC), BMI is the best metric for population-level assessment of overweight and obesity.[33] BMI, the main exposure measure, represents an inexpensive alternative to direct measures of body fat and has the additional benefit of being easy to use for both clinicians and the general public. Although BMI is calculated the same way for children and adults (weight in kilograms divided by squared height in meters), the criteria used to interpret the meaning of the BMI values is different for children. This is due to the fact that the amount of body fat changes with age and it differs between girls and boys. Therefore, the BMI values for children ages 2 to 20 years are translated into a percentile for age and sex.[34] The percentile ranges for the BMI-for-age categorization are presented in Table 1.

Primary Dependent Variable

The primary dependent variable was created as a dichotomous variable, specifically an Abbreviated Injury Scale (AIS) score of 3 or more as compared to an AIS score of 2 or less (see Table 1). AIS scores range from 1 to 6 including: 0 = no injury, 1 = minor, 2 = moderate, 3 = serious, 4 = severe, 5 = critical and 6 = maximum.[35]

Rationale for Selection of Additional Covariates

The additional covariates selected for analysis from the NASS CDS were based on evidence from published research and our experience in previous analyses with this database.These covariates are listed in Table 1. The selected covariates have been demonstrated to have independent effects on injury severity and may modify the effects of other variables. Among the demographic and personal factors affecting risk of serious injury, we included age because of its strong, independent non-linear relationship with injury in children, even after adjusting for MVC characteristics.[36]

Variables related to crash characteristics included restraint use, seat position, the age of the vehicle, and rollovers. Seating position, especially as this variable relates to near-sided impacts and rollovers, must be taken into account when examining severe injuries from MVCs. In a previous report, Brown et al. (2006) found that injury severity was greater for those children seated in the front versus the back seat regardless of crash direction.[37] Similarly, Durbin et al. (2005) found that children who were seated in the front seat were at 40% greater risk of injury as compared with children in the rear seat, and Viano and Parenteau (2008) found children aged 0 to 7 years who are seated in the second row (back seat) while in nearside impacts and rollovers, are at the highest risk of injury.[38 39]

Change in velocity and principal direction of force, variables related to crash severity, were both included in the analysis. Nance et al. (2006) found that change in velocity (delta V) is strongly predictive of injury risk for child occupants.[40] In addition, principal direction of force was important to evaluate because side impact collisions, in particular, account for a large proportion of injuries and death to child passenger vehicle occupants.[41]

Table 1. Variables considered in the analysis

	Variable	Type	Categories
1	**Abbreviated Injury Scale (AIS)** (Primary dependent variable)	Dichotomous	Moderate to no injury (0, reference) 0= No injury 1= Minor injury 2= Moderate injury Serious injury to death (1) 3=Serious injury 4=Severe injury 5=Critical injury 6=Maximum
2	**Body Mass Index (BMI) for Age** (Primary independent variable)	Ordinal	▪ <5th percentile= Underweight ▪ 5th-<85th percentile =Normal weight (reference) ▪ 85th-<95th percentile= Overweight ▪ ≥95th percentile= Obese ▪ ≥99th percentile= Severely obese
3	**Age (years)**	Continuous	2-14 years of age
4	**Gender**	Dichotomous	Male (reference) Female
	<u>Crash Characteristics</u>		
5	**Restraint use**	Dichotomous	Proper use No restraint use (reference)
6	**Seat position**	Dichotomous	Front seat (passenger seat only) Back seat (reference)
7	**Rollovers**	Dichotomous	Yes No (reference)
8	**Age of vehicle**	Continuous	0-60 years
	Crash Severity		
9	**Change in velocity (km/hr)**	Continuous	5-50 km/hr
10	**Principal direction of force**	Nominal	Side impact collision Rear collision (reference)

Institutional Review Board

All necessary steps were taken to ensure patient safety, privacy and confidentiality. The Oregon Health & Science University (OHSU) Institutional Review Board (IRB) determined that our secondary analysis of de-identified data in a public use data source does not meet the definition of human subject research (IRB00005213). HIPAA regulations do not apply because the activity does not involve the collection, use, or disclosure of Protected Health Information.

Statistical Analysis

Statistical analyses were conducted using Stata 10.[42] In order to investigate the relationship between BMI-for-age and severe injury, a multivariate logistic regression model was created. We used calculated sample weights to account for the complex sampling design of NASS CDS.[43] A logistic regression model was selected as the analytic approach because the outcome variable (injury severity) was classified as a dichotomous variable. In addition, this approach provides an effective analytical tool to control for confounding effects and to assess effect modification. Although common epidemiologic methodology supports the inclusion of all clinically and intuitively relevant variables in the final model, regardless of their statistical significance, this approach can lead to overfitting which is "typically characterized by unrealistic large estimated coefficients and estimated standard errors".[44] Therefore, we sought to construct the most parsimonious model restricted to variables with empirical significance, and variables consistently demonstrated to be associated with crash injury severity in previous studies.

We first calculated incidence estimates and 95% confidence intervals (CIs) of moderate to no-injury, and serious injury to death pediatric cases by levels of independent variables. In turn, univariate logistic regression models were built to examine associations between each independent variable and the covariates. We used Wald F statistics and their associated p-values to assess statistical significance, and associations were expressed as unadjusted odds ratios (ORs) and 95% CIs.

Each of the independent variables was evaluated for association with the primary outcome variable, through the use of univariate logistic regression. Those variables that were found to be associated with the primary outcome variable, with p-values ≤ 0.30, as well as those variables suspected to represent potential confounders were considered for inclusion in the multivariate model. The selected candidate variables as well as variables identified as potential confounders, were entered into a multivariate logistic regression model where p-values ≤ 0.05 were considered significant.

Crash severity represents a major potential confounder and was specifically adjusted for by examining change in velocity and principal direction of force. In addition, seatbelt use, airbag deployment, seat position and rollovers served to adjust for crash characteristics (Table 1). Variables such as age, gender, and the principal direction of force, represent possible effect modifiers in the association between BMI and injury in motor vehicle crashes, and were evaluated for possible interactions. The choice to evaluate these potential interactions is based on existing literature.[45 46]

Multivariate logistic regression analysis was performed starting with all independent variables in the model that met the preliminary significance level. Using a backwards elimination procedure, independent variables were removed singly from the full model, starting with the least significant, until the model contained only variables with ß coefficient *p*-values ≤ 0.05 and those chosen *a priori*. We considered deviance scores (-2 Log Likelihood) in arriving at the most parsimonious main-effects model.

Table 2. Sample Characteristics of Pediatric (2-14 years) Motor Vehicle Crash Occupants by Weight, 1995-2006

	Entire Sample (N=10,818)	**N**	**Missing, %**	**Analysis Sample** (N=7689)	**N**
Age, mean ± SD	8.01 ± 3.92	10818	0 (0%)	8.2 ± 3.93	7693
Gender		10794	24 (0.02%)		7689
Male	5541 (50.8%)			3919 (51.6%)	
Female	5253(49.2%)			3770 (48.4%)	
Height (m), mean ±SD	1.27 ± 0.30	8913	2989 (27.6%)	1.28 ± 0.30	7693
Weight (kg), mean ± SD	34.23 ± 17.9	9627	2439 (22.5%)	34.93 ± 18.01	7693
Crash Severity					
Change in velocity (km/hr)	24.5 ± 12.6	6267	4551 (42.1%)	24.0 ± 12.4	4683
PDOF, %		7112	4650 (43.0%)		4728
Side impact	1793 (24.5%)			1155 (26.1%)	
Other	5319 (75.5%)			3573 (73.9%)	
Crash Characteristics					
Restraint Use, %		7154	3664 (33.9%)		5007
Proper restraint	3679 (63.7%)			2978 (70.3%)	
Improper restraint	275 (3.0%)			236 (3.8%)	
None	3200 (33.3%)			1793 (25.9%)	
Seat positions, %		10589	229 (2.1%)		7600
Front seat	3169 (31.7%)			2336 (30.7%)	
Back seat	7420 (68.3%)			5264 (69.3%)	
Rollovers, %		10678	140 (1.3%)		7596
Yes	1255 (10.2%)			942 (12.1%)	
No	9423 (89.8%)			6654 (87.9%)	
Vehicle Age, mean ± SD	6.60 ± 5.36	10816	2 (0.0%)	6.68 ± 5.40	7691

*Values reflect absolute numbers and percentages are weighted

Table 3. Sample Characteristics of Pediatric (2-14 years) Motor Vehicle Crash Occupants by BMI-for-age, 1995-2006 (N=7608 representing 3,950,164 children)

	Under-weight	**Normal**	**Over-weight**	**Obese**	**Severely Obese**
Serious Injury, % (N=7608)					
AIS ≥3 (554) 1.2%	49 (1.4%)	250 (1.2%)	87 (1.6%)	79 (1.1%)	89 (1.2%)
AIS ≤2 (7054) 98.8%	557 (98.6%)	2941 (98.8%)	1027 (98.4%)	998 (98.9%)	1531 (98.8%)
Gender, % (N=7689)					
Male (3919) 51.6%	295 (42.8%)	1517 (46.3%)	596 (55.4%)	598 (58.8%)	913 (58.5%)
Female (3770) 48.4%	276 (57.3%)	1728 (53.7%)	538 (44.6%)	503 (41.5%)	725 (41.5%)
PDOF, % (N=4728)					
Side impact (1155) 26.3%	92 (40.1%)	498 (24.5%)	166 (23.5%)	162 (25.0%)	236 (25.9%)
Other (3573) 73.7%	289 (59.4%)	1465 (75.5%)	550 (76.5%)	519 (75.0%)	747 (74.1%)
Restraint Use, % (N=5007)					
Proper (2977) 70.4%	243 (72.2%)	1328 (70.0%)	424 (78.8%)	405 (72.9%)	577 (62.9%)
Improper (236) 4.7%	25 (7.2%)	80 (3.0%)	29 (1.5%)	24 (1.4%)	78 (7.8%)
None (1791) 25.8%	112 (20.7%)	762 (27.2%)	261 (19.7%)	267 (25.7%)	389 (29.4%)
Seating Position, % (N=7596)					
Front (2334) 30.6%	119 (30.2%)	1118 (35.2%)	417 (40.8%)	358 (28.7%)	322 (15.1%)
Other (5262) 69.4%	447 (69.8%)	2080 (64.8%)	702 (59.2%)	730 (71.3%)	1303 (84.9%)
Rollovers, % (N=7592)					
Yes (942) 12.2%	71 (5.7%)	385 (13.4%)	142 (17.8%)	140 (11.5%)	216 (8.3%)
No (6650) 87.8%	539 (94.3%)	2817 (86.6%)	981 (82.2%)	943 (88.5%)	1424 (91.7%)

*Values reflect absolute numbers and percentages are weighted

Table 4. Univariate Analysis Results, Serious Pediatric (2-14 years) Injuries (AIS ≥ 3) from Motor Vehicle Crash Occupants by BMI-for-age, 1995-2006

	Odds Ratio	***p***	**95% Confidence Interval**
Underweight	1.22	0.57	0.58-2.57
Overweight	1.55	0.37	0.68-3.53
Obese	0.83	0.39	0.53-1.30
Severely Obese	0.95	0.85	0.53-1.71
Age	1.04	0.08	0.99-1.09
Gender			
Female	0.99	0.93	0.72-1.36
Crash Characteristics			
Restraint Use			
Proper Restraint	0.27	0.00	0.17-0.43
Seating Position			
Front Seat	1.88	0.00	1.41-2.52
Rollover	2.01	0.01	1.19-3.39
Vehicle Age	1.01	0.25	0.99-1.04
Crash Severity			
Change in Velocity	1.10	0.00	1.07-1.13
Principal Direction of Force			
Side Collision	0.95	0.79	0.65-1.40

*Values are weighted

RESULTS

Descriptive Data

A total of 10,818 children 2-14 years of age were involved in motor vehicle crashes in the United States from 1995-2006, the established study period. After removing children who had missing data on either weight or height, and adjusting for outliers, the sample size was reduced to 7,689.

The characteristics of subjects and motor vehicle crashes are presented in Table 2. The average age of the study subjects was 8.2 years old with males and females being represented almost equally (51.6% and 48.4%, respectively). The mean child height and weight was 1.28 meters and 34.93 kg, respectively. Approximately, seventy percent (70.3%) of children were properly restrained in either a child safety seat and/or a seatbelt while only 3.8% of children were improperly restrained. Therefore, in the NASS CDS, over a quarter of children (33.3%) were recorded as unrestrained during the car crash. When considering seating position, the overwhelming majority of children (69.3%) were seated in the back seat of the vehicle involved in the crash. In addition, only 12.1% of the motor vehicle crashes were recorded as having had a rollover (includes any degree of rollover). The average age of the vehicles involved in crashes was 6.68 years. In regards to principal direction of force, which was selected as a proxy for crash severity, over one quarter of children (26.1%) in this sample experienced motor vehicle crashes that involved a side impact collision.

Table 3 presents the injury distribution and case characteristics by BMI-for-age category for those cases where BMI-for-age was calculable (no missing values for weight of height). The injury distribution included 98.8% of children who suffered minor or no injuries ($AIS \leq 2$) as compared to 1.2% of children who suffered severe or fatal injuries ($AIS \geq 3$). Of those children who were seriously injured, a total of 7.2% were considered underweight, 48.0% were considered normal weight, 16.8% were considered overweight, 17.1% were considered obese and 10.9% were considered severely obese.

Univariate logistic regression was employed as a means of evaluating the crude association of each independent variable with serious injury, the primary outcome variable (Table 4). The following variables were found to be associated with severe injury ($AIS \geq 3$) at a *p*-value ≤ 0.30: proper restraint, front seated position, rollover, vehicle age, and change in velocity. In addition, this analysis served to confirm other previously identified risk factors for injury related to MVCs among the pediatric population, including: the proper use of restraint systems, rollovers and sitting in the front passenger seat of the vehicle and change in velocity.

Logistic Regression Model

After the backwards elimination process, the final model presented in Table 5, includes the primary independent variable of interest, BMI-for-age, as well as age, gender, proper restraint, front seat position, rollover, vehicle age, change in velocity, and side impact collision (Table 5). Children classified as overweight were found to be at a significantly greater risk of serious injuries and death, as compared to normal weight children (OR=3.89, 95% CI: 1.55-9.76). Therefore, we failed to reject the null hypothesis that the risk of serious injury including death ($AIS \geq 3$) is the same for obese children relative to children with normal BMI-for-age.

Table 5. Final logistic regression analysis of the association between BMI-for-age and serious pediatric motor vehicle crash injury

(N=1,867 observations in final model, representing a population of 863,585 children)

	Odds Ratio	*p*	95% Confidence Interval
Underweight	1.45	0.49	0.47-4.49
Overweight	3.89	0.01	1.55-9.76
Obese	2.37	0.16	0.68-8.24
Severe Obese	0.98	0.98	0.20-4.81
Age	1.06	0.28	0.95-1.17
Gender			
Female	0.64	0.03	0.43-0.94
Crash Characteristics			
Restraint Use			
Proper restraint	0.12	0.00	0.06-0.26
Seating Position			
Front seat	0.76	0.69	0.17-3.35
Rollover	1.04	0.93	0.44-2.46
Vehicle Age	0.99	0.70	0.91-1.07
Crash Severity			
Change in Velocity	1.12	0.00	1.10-1.15
PDOF			
Side Impact	2.51	0.01	1.27-4.95

The alternate logistic regression model presented in Table 6 was created to evaluate the sensitivity of BMI-for-age effect estimates when excluding two specific measures of crash severity. Although the elimination of change in velocity and principle direction of force successfully increased the sample size available for analysis, it did not produce a statistically significant association between serious injury and pediatric MVC occupants in any BMI-for-age category. A second sensitivity analysis was conducted to explore the classification of BMI-for-age into four categories, reflecting the collapse of obese and severely obese into a single category, as compared to employing five categories of BMI-for-age where obese and severely obese are presented as distinct categories. Neither model demonstrated that obese children were at an increased risk of serious injury. Based on the fact that there is no significant difference when the fifth category of BMI-for-age, severely obese, was included as an independent category, we elected to examine the five categories of BMI-for-age.

Table 6. Alternate logistic regression model of the association between BMI-for-age and serious pediatric motor vehicle crash injury excluding covariates related to crash severity

(N=4,528 observations in final model, representing a population of 2,652,868 children)

	Odds Ratio	*p*	**95% Confidence Interval**
Underweight	1.93	0.12	0.82-4.51
Overweight	1.29	0.48	0.60-2.77
Obese	1.04	0.91	0.51-2.10
Severe Obese	1.63	0.32	0.59-4.48
Age	1.05	0.08	0.99-1.12
Gender			
Female	1.02	0.95	0.61-1.70
Crash Characteristics			
Restraint Use			
Proper restraint	0.23	0.00	0.16-0.32
Seating Position			
Front seat	1.89	0.03	1.09-3.28
Rollover	1.16	0.65	0.59-2.27
Vehicle Age	0.97	0.28	0.92-1.02

DISCUSSION

A) Main Conclusions:

We examined the effect of BMI-for-age on the risk of serious injury (AIS ≥ 3) among children aged 2-14 years who were involved in car crashes in the United States over an 11-year period. In our analysis of national cross-sectional data, children classified as overweight were found to be at a significantly greater risk of serious injuries and death, as compared to normal weight children (OR=3.89, 95% CI: 1.55-9.76).

B) Comparison with Other Studies:

Our findings are consistent with a recent study of vehicular trauma patients, ages 16 and older, by Ryb and Dischinger (2008) that found overweight patients, but not obese patients, experienced more severe motor vehicle crash injuries and death (OR = 2.44, p = 0.009).[47] Ryb and Dischinger controlled for the majority of occupant and crash factors that we considered in our analysis: injury severity, BMI, age, gender, restraint use, change in velocity and principle direction of force). We additionally accounted for seat position, rollovers and the age of the vehicle at the time of collision. On the other hand, Ryb and Dischinger (2008) specifically controlled for occupant height and curb weight, which we did not.[48] Other than the age of the study subjects, the greatest differences between our respective studies were the databases used and the time period of interest. Specifically, Ryb and Dischinger (2008) chose to analyze data from the CIREN database over a five-year period, while we analyzed data from the NASS CDS over an eleven-year period.

Pollack et al. (2008), in their recent cross-sectional study of motor vehicle crash injury risk among children 9-15 years of age, found that overweight and obese children are not at increased overall risk of injury.[49] However, this finding may be misleading. While this analysis demonstrated that *overall* risk of injury was not elevated, overweight and obese adults were at increased risk of injury to both upper and lower extremities.[50] These findings may suggest a potential limitation to our analysis, which utilizes a nonspecific overall injury risk outcome and does not separately consider injury risk to specific body regions. However, Zaveri et al. (2009), in their analysis of data for children ages 2-17 years, found no significant associations between overweight and overall injury (defined as AIS>1), nor an association with injury to a specific body region.[51] Clearly, differences in the definition of the outcome probably explain the differences observed in study designs to demonstrate an association.

C) Strengths and Potential Limitations:

When interpreting these results, there are some strengths and potential limitations that need to be considered. To account for potential confounding, we adjusted for several covariates in the multivariate analysis, related to specific crash characteristics, known risk factors and crash severity. Excluding two covariates related to crash severity (change in velocity and principal direction of force) increases the number of observations available for analysis (Table 6), and theoretically creates a more inclusive and therefore representative data set and improves statistical power. However, the magnitude of the associations between BMI-for-age and serious injury were greatly reduced in the second model and were not statistically significant. We believe that this is the result of negative

confounding by these crash severity factors, and place more confidence in our model that adjusts for these factors. The inclusion of change in velocity and principal direction of force produces effect measure estimates that more accurately reflect the complex injury mechanism at play. Even though we have no reason to suspect nondifferential bias due to missing data on these factors, our sensitivity analysis give us caution and we cannot confidently rule out bias associated with the use of the restricted data set. The final model included a relatively limited sample size of 1,867 study subjects, which represented 863,585 children nationwide, given the complex weighting scheme.
The fact that a large proportion of the study population was eliminated from the final analytic data set because they were missing data on the following variables represents a potential limitation of the study: change in velocity (40.0% missing), principal direction of force (45.6% missing) and restraint use (34.1% missing).

Although a large proportion of the subjects, 28.3%, were initially excluded due to missing weight and/or height values, there is not an immediately apparent reason to believe that these 3,058 subjects were more likely to be obese children or more likely to have serious injuries or death. There was no substantial difference found in regards to injury severity among cases that were excluded due to missing weight and/or height values and those cases for whom which the information was available. However, we don't believe that the exclusion of these values had any significant impact on the estimate of the BMI-for-age effect measures beyond a reduction of the precision. Although it was outside of the scope of this particular project, it may be beneficial for future researchers to employ multiple imputation methods to address the challenge of missing data in the NASS CDS database.

There are limitations to using BMI-for-age as a measurement of obesity including the possibility of inaccurate measurement of weight and/or height, which could by extension, contribute to an inaccurate calculation of BMI and thus a misclassification of the BMI-for-age category. The potential for misclassification bias also may exist among cases in which the child's height or weight was reported by a parent, rather than by a clinician. However, previous examination of parent-reported height and weight measurements have been found to be reasonably valid when used to classify children in large epidemiological studies.[52] When considering potential bias, it is also possible that a misclassification of restraint use exists as there is a tendency to over-report seatbelt use.[53] This issue is further complicated by the fact that overweight, obese and extremely obese people are associated with significantly decreased use of seatbelts, which is thought to be due to a lack of physical comfort.[54]

Our secondary analysis is reliant on the quality of data collected in the NASS CDS. Because NASS CDS data are gathered by experts in the field and subject to rigorous quality control measures, concerns about measurement accuracy are reduced.[55] It is also important to recognize that the NASS CDS database is inherently biased toward more severe collisions, as it is limited to collisions in which at least one vehicle was towed away.[56] The complex sampling design employed by the NASS CDS database makes it possible to calculate statistical estimates that are nationally representative, which we consider to be a strength of this study, as well as the extensive variety of variables available for each crash.

Lastly, given the fact that the percentage of children with an AIS score of 3 or greater was very small (1.24%), it is important to note that logistic regressions can lack robustness when the outcome is very rare. Despite the potential limitations we've discussed, this study is valuable in its ability to increase the knowledge base about the relationship between BMI-for-age and motor vehicle crash injury severity in the pediatric population.

D) Public Health Implications:

The results of our research serve to contribute to the rather limited body of literature related to the relationship between BMI-for-age and injury severity among pediatric motor vehicle crash occupants. Based on our results, those children who were properly restrained were found to have an 88% reduction in serious injury. This strong protective effect was stable in both the final model (Table 5) and the alternate model developed as part of the sensitivity analysis (Table 6). This finding underscores the importance of existing public health campaigns that encourage parents to properly restrain their children to achieve effective injury reduction.

Previous research reveals an association between increased BMI among adults and a decrease in the use of seatbelts.[56 57] A parent's decision not to wear their safety belt or to wear it improperly may influence a child's beliefs and behaviors around the importance of proper seatbelt use. Exploring the impact of parental modeling related to seatbelt adherence represents an interesting area for future research and may provide a window for valuable intervention.

As the rates of pediatric overweight and obesity increase, research efforts should continued to be made to gain a better understanding about the role of body habitus on the risk of motor vehicle crash injury and death. F studies should be aimed at elucidating the role of physiology and biomechanical factors in serious injury among both overweight and obese children involved in motor vehicle crashes.

Given the dramatic increase in the prevalence of childhood obesity in the U.S., it is critical that the public health professionals identify and address the multiple areas of children's health impacted by the obesity epidemic. Given the large number of children involved in motor vehicle crashes each year in the United States, and the fact motor vehicle crashes are the leading cause of death and disability in children, motor vehicle crashes represent an important area for research, potentially informing prevention education and engineering interventions.

Table 5. Final logistic regression analysis of the association between BMI-for-age and serious pediatric motor vehicle crash injury

(N=1,867 observations in final model, representing a population of 863,585 children)

	Odds Ratio	*p*	**95% Confidence Interval**
Underweight	1.45	0.49	0.47-4.49
Overweight	3.89	0.01	1.55-9.76
Obese	2.37	0.16	0.68-8.24
Severe Obese	0.98	0.98	0.20-4.81
Age	1.06	0.28	0.95-1.17
Gender			
Female	0.64	0.03	0.43-0.94
Crash Characteristics			
Restraint Use			
Proper restraint	0.12	0.00	0.06-0.26
Seating Position			
Front seat	0.76	0.69	0.17-3.35
Rollover	1.04	0.93	0.44-2.46
Vehicle Age	0.99	0.70	0.91-1.07
Crash Severity			
Change in Velocity	1.12	0.00	1.10-1.15
PDOF			
Side Impact	2.51	0.01	1.27-4.95

The alternate logistic regression model presented in Table 6 was created to evaluate the sensitivity of BMI-for-age effect estimates when excluding two specific measures of crash severity. Although the elimination of change in velocity and principle direction of force successfully increased the sample size available for analysis, it did not produce a statistically significant association between serious injury and pediatric MVC occupants in any BMI-for-age category. A second sensitivity analysis was conducted to explore the classification of BMI-for-age into four categories, reflecting the collapse of obese and severely obese into a single category, as compared to employing five categories of BMI-for-age where obese and severely obese are presented as distinct categories. Neither model demonstrated that obese children were at an increased risk of serious injury. Based on the fact that there is no significant difference when the fifth category of BMI-for-age, severely obese, was included as an independent category, we elected to examine the five categories of BMI-for-age.

Table 6. Alternate logistic regression model of the association between BMI-for-age and serious pediatric motor vehicle crash injury <u>excluding covariates related to crash severity</u>

(N=4,528 observations in final model, representing a population of 2,652,868 children)

	Odds Ratio	*p*	**95% Confidence Interval**
Underweight	1.93	0.12	0.82-4.51
Overweight	1.29	0.48	0.60-2.77
Obese	1.04	0.91	0.51-2.10
Severe Obese	1.63	0.32	0.59-4.48
Age	1.05	0.08	0.99-1.12
Gender			
Female	1.02	0.95	0.61-1.70
Crash Characteristics			
Restraint Use			
Proper restraint	0.23	0.00	0.16-0.32
Seating Position			
Front seat	1.89	0.03	1.09-3.28
Rollover	1.16	0.65	0.59-2.27
Vehicle Age	0.97	0.28	0.92-1.02

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