



OPEN ACCESS

EDITED BY

Vincenzo Pota,
University of Campania Luigi Vanvitelli, Italy

REVIEWED BY

Marco Fiore,
Università degli Studi della Campania 'Luigi Vanvitelli', Italy
Rachel Colbran,
Stanford University, United States

*CORRESPONDENCE

Mark Ulrich Gerbershagen
✉ mark.gerbershagen@uni-wh.de

RECEIVED 05 November 2025

REVISED 09 December 2025

ACCEPTED 13 January 2026

PUBLISHED 09 February 2026

CITATION

Schnabel TM, Scherer N, Böhmer AB, Lefering R and Gerbershagen MU (2026) Impact of the body mass index on the intensive care outcome of (poly-)traumatized patients. *Front. Anesthesiol.* 5:1740319. doi: 10.3389/fanes.2026.1740319

COPYRIGHT

© 2026 Schnabel, Scherer, Böhmer, Lefering and Gerbershagen. This is an open-access article distributed under the terms of the [Creative Commons Attribution License \(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Impact of the body mass index on the intensive care outcome of (poly-)traumatized patients

Timon Marvin Schnabel¹, Natalie Scherer¹, Andreas B. Böhmer², Rolf Lefering³ and Mark Ulrich Gerbershagen^{1*}

¹Department of Anaesthesiology, University Witten/Herdecke, Cologne, Germany, ²Department of Anaesthesiology and Operative Intensive Care, University Witten/Herdecke, Cologne Merheim Medical Centre, Cologne, Germany, ³Institute for Research in Operative Medicine (IFOM), University Witten/Herdecke, Cologne, Germany

Purpose: The increasing prevalence of obesity poses significant challenges to intensive care medicine, particularly in trauma care. The “obesity paradox”, suggesting enhanced survival in overweight individuals, remains controversial. The study aimed to investigate the association between Body Mass Index and intensive care outcomes in severely injured patients.

Methods: A retrospective matched 1:2:1 set analysis with $n = 192/384/192$ patients was conducted using data from the TraumaRegister DGU[®]. A total of 5,766 patients admitted to intensive care were included and categorized into three BMI groups: underweight ($\leq 20 \text{ kg/m}^2$), normal weight/overweight ($20.1\text{--}29.9 \text{ kg/m}^2$), and obese ($\geq 30 \text{ kg/m}^2$). The application of World Health Organization classification was precluded on statistical grounds. A subgroup of polytraumatized patients ($n = 272$) was separately analyzed. Outcomes included the duration of mechanical ventilation, ICU stay, organ failure, and in-hospital mortality.

Results: BMI was positively associated with organ failure, especially cardiac ($p = 0.001$) and pulmonary failure ($p = 0.001$). The mortality rate was twice as high for obese patients as for underweight patients in the matched cohort [Group III: 10.4%; Group I: 5.2%; p (linear trend) = 0.025]. Ventilation time increased significantly with higher BMI ($p = 0.012$).

Conclusion: In this cohort, there was an absence of evidence to support the notion of an “obesity paradox”. Overweight and obesity were not associated with improved survival and were instead linked to less favorable intensive care outcomes following severe trauma, although absolute differences in mortality were modest.

Trial registration: ID 2014-021.

KEYWORDS

body mass index (BMI), critical care outcome, intensive care unit (ICU) stay, obesity paradox, organFailure, polytrauma

1 Introduction

In recent decades, the proportion of people who are overweight or obese has increased significantly worldwide, making this trend a central focus of international health research. In 2022, the World Health Organization (WHO) reported that 43% of the world's population over the age of 18 were overweight ($\geq 25.0 \text{ kg/m}^2$) and 16% were classified as obese ($\geq 30.0 \text{ kg/m}^2$), more than doubling the number of obese

people since 1990 (1). As the global community confronts an escalating prevalence of obesity, the management of critically ill obese patients is assuming increasing significance on the global stage.

In Germany, national statistics corroborate this trend. In 2021, 71.4% of adults were classified as overweight, and 33.5% as obese, with a higher prevalence observed among men (2). The contributing factors to this phenomenon include sedentary lifestyles, high-calorie diets, insufficient physical activity, short sleep duration, and chronic stress. Furthermore, a strong correlation has been demonstrated between obesity and psychosocial factors, including depression, socioeconomic status, and behavioral disorders such as binge eating (3).

The Body Mass Index (BMI), calculated as body weight divided by height squared (kg/m^2), remains the most commonly used tool for categorizing body weight. It is independent of age and sex and is endorsed by the WHO as a standard global measure (4). However, it is important to acknowledge the limitations of BMI. Firstly, it does not differentiate between fat and muscle mass. Secondly, it does not consider fat distribution or age-related physiological variations (5). Furthermore, BMI alone provides limited insight into an individual's metabolic health or obesity-related comorbidities (6) and does not differentiate between ethnic groups (7). This limitation of BMI should be considered in relation to the analysis of the relationship between outcome and BMI. As an alternative, anthropometric measures such as waist circumference, waist-to-hip ratio, and direct assessment of body composition may offer a more nuanced understanding of the risks associated with obesity (8). Despite these limitations, the BMI continues to serve as a standard parameter in clinical research, documentation and trauma registers, including the TraumaRegister DGU[®], underscoring its practical application.

It is worthy of note that a number of clinical studies have identified what has been termed an “obesity paradox”. This is a phenomenon in which patients who are overweight or mildly obese exhibit unexpectedly better outcomes in certain disease contexts, such as heart failure, sepsis and trauma (9–11). One hypothesis to explain the obesity paradox is that the excess fat in obese patients functions as a metabolic reserve during periods of acute illness (12). Alternatively, the excess fat may act as an immune modulator (13) or may alter the pharmacokinetics of the used agents during treatment (14, 15). Nevertheless, this phenomenon remains controversial, particularly in the context of trauma. A number of authors have reported an increased mortality and complications in obese trauma patients, whilst others have observed a neutral or protective effect (16–19). A pivotal element in the discourse surrounding the obesity paradox pertains to methodological disparities, including the

divergent conceptualizations of obesity and the range of BMI limits employed. Furthermore, confounders such as nutritional status, sarcopenic obesity, or selection bias have the potential to engender inconsistency in the studies (10, 13, 16, 20).

Concurrently, underweight individuals represent a vulnerable demographic, particularly within the context of critical care. Lower physiological reserves, reduced immune capacity, and increased risk of early mortality have been identified as contributing factors for increased mortality in critically ill underweight patients (18, 21–24).

The management of trauma, and especially polytrauma, poses unique challenges for intensive care. In addition to the severity of the injury, individual factors such as nutritional status and comorbidities (e.g., coronary heart disease) have been demonstrated to have a significant impact on outcomes such as organ failure, length of stay, duration of mechanical ventilation, and mortality (25, 26). The association between obesity and a pro-inflammatory state (13), as well as impaired respiratory mechanics (27) altered pharmacokinetics (14, 15), and mobilization (20) has been documented. These factors have the potential to complicate the management of intensive care and the recovery process following trauma.

Nevertheless, the existing body of evidence pertaining to the relationship between obesity and outcomes following trauma remains equivocal and elusive. A number of studies have reported increased mortality and risks of poor outcome, while others suggest a neutral or even protective effect for obese patient in critical care (9–11, 13, 14, 28–30). This study therefore investigates the influence of BMI on the intensive care course of (poly-) traumatized patients. Utilizing a retrospective dataset from the “TraumaRegister DGU[®]”, the study explores the correlation between BMI and several key outcomes, including Intensive Care Unit (ICU) length of stay, duration of ventilation, organ failure, and survival. A particular focus of the study is the validation of the obesity paradox in trauma settings.

2 Material and methods

The present study is based on data from the TraumaRegister DGU[®] (TR-DGU) of the German Trauma Society (Deutsche Gesellschaft für Unfallchirurgie, DGU) founded in 1993. The aim of this multi-center database is a pseudonymized and standardized documentation of severely injured patients.

Data are collected prospectively in four consecutive time phases from the site of the accident until discharge from hospital: A) Pre-hospital phase, B) Emergency room and initial surgery, C) Intensive care unit and D) Discharge. The documentation includes detailed information on demographics, injury pattern, comorbidities, pre- and in-hospital management, course on the intensive care unit (ICU), relevant laboratory findings including data on transfusion, and outcome of each individual. The inclusion criterion is admission to hospital via the emergency room (trauma team activation) with subsequent intensive or intermediate care. Patients who reached the hospital

Abbreviations

AIS, abbreviated injury scale; ASA, American Society of Anesthesiologists; BE, base excess; BMI, body mass index; cm, centimeter; CT, computed tomography; ER, emergency room; Hb, hemoglobin level; ICU, intensive care unit; ISS, injury severity score; kg, kilogram; lin., linear; MOF, multiple organ failure; m^2 , square meter; SIRS, Systemic Inflammatory Response Syndrome; SOFA, Sepsis-related Organ Failure Assessment; WHO, World Health Organization.

with vital signs but died before admission to ICU were included as well.

The infrastructure for documentation, data management, and data analysis is provided by AUC - Academy for Trauma Surgery (AUC - Akademie der Unfallchirurgie GmbH), a company affiliated to the German Trauma Society. The scientific leadership is provided by the Committee on Emergency Medicine, Intensive Care and Trauma Management (Sektion NIS) of the German Trauma Society. The participating hospitals submit their data pseudonymized into a central database via a web-based application. Scientific data analysis is approved according to a peer review procedure laid down in the publication guideline of TR-DGU.

The participating hospitals are primarily located in Germany (90%), but a rising number of hospitals of other countries contribute data as well (presently Austria, Belgium, Finland, Luxembourg, Slovenia, Switzerland, The Netherlands, and the United Arab Emirates). Currently, approx. 30,000 cases from over 650 hospitals are entered into the database per year. Participation in TR-DGU is voluntary. For hospitals associated with TraumaNetzwerk DGU[®], however, the entry of at least a basic dataset is mandatory for reasons of quality assurance.

This study was conducted according to the publication guideline of the TR-DGU and registered as project number ID 2014-021.

This retrospective analysis focused on registry data of patients admitted in the years 2005 to 2009, as the documentation of height and weight was included in the standard documentation only until 2009. During this period, BMI was available principally for patients documented with the standard dataset, such that the analyzed cohort represents a subset of the overall TR-DGU[®] population. It is not possible to exclude systematic differences between patients with and without complete BMI documentation. Consequently, when interpreting the external validity of our findings, it is important to consider that the study reflects trauma and intensive care management practices of the mid-2000s rather than contemporary care.

Patients were included if they met the following criteria:

- Age ≥ 16 years
- Injury Severity Score (ISS) ≥ 9
- Admission to the ICU
- Documented with standard dataset
- Weight and height available for BMI
- Available information on the occurrence of organ failure (respiratory, coagulation, liver, cardiovascular, central nervous system, renal), multi-organ failure (MOF), and sepsis

The ISS threshold (≥ 9) ensured the inclusion of at least moderately injured patients or those with a serious isolated injury.

Based on BMI at hospital admission, patients were divided into three categories:

- Group I (Underweight): BMI ≤ 20 kg/m² $n = 284$ (4.9%)
- Group II (Normal weight and overweight): BMI 20.1–29.9 kg/m² $n = 4,722$ (81.9%)
- Group III (Obesity): BMI ≥ 30 kg/m² $n = 760$ (13.2%)

Underweight according to the WHO classification (BMI ≤ 18.5 kg/m²) was rare with just 100 cases (1.7%); as well as morbid obesity (BMI ≥ 35 kg/m²) with 225 patients (3.9%). Therefore, the cut-off values for the present analysis were set at BMI ≤ 20 and BMI ≥ 30 . Utilizing the complete WHO classification would thus have resulted in exceedingly diminutive strata at the extremes, particularly within the matched cohort, thereby engendering constrained statistical potency and unstable estimates. Consequently, three broader categories with adequate sample size and clinical interpretability were pre-specified: a low-BMI group (≤ 20 kg/m²), a reference group comprising normal weight and overweight (20.1–29.9 kg/m²), and an obese group (≥ 30 kg/m², corresponding to at least WHO class I obesity). The application of these categories enabled the construction of a clinically intuitive gradient across BMI, while circumventing the occurrence of sparse data problems within the underweight and morbidly obese ranges.

From the original 5,766 eligible trauma cases, a matched cohort of 768 patients was constructed using a 1:2:1 ratio (192 underweight, 384 normal and overweight, 192 obese). Patients were matched according to the following criteria:

- Sex (male/female)
- Four age groups (16–30, 31–49, 50–69, ≥ 70 years)
- Serious injury (AIS severity ≥ 3 , or not) in the following four body regions: head, thorax, abdomen, extremities
- Type of treatment (surgical/conservative)

The subgroup of polytrauma was defined as having a serious injury in at least 2 body regions. This definition applied to 36.4% of the matched population ($n = 272$). All analyses were conducted in the total cohort and were repeated within this subgroup. The imposition of exact matching on the predefined categorical variables (sex, age groups, AIS ≥ 3 in four body regions, and type of treatment) by the matching algorithm resulted in the distribution of these variables becoming identical across the BMI groups within the matched cohort. Consequently, standardised measures of balance, such as standardised mean differences, would inherently be equal to zero for these variables by design. For the covariates that were not part of the matching algorithm, baseline characteristics are presented descriptively in Table 2, and potential residual imbalances are addressed in the Discussion.

The demographic variables included age, sex, height, weight, BMI, and American Society of Anaesthesiologists (ASA) score. The data collected included all injuries (ISS, number of diagnoses), the mechanism of injury (e.g., traffic accident, fall), laboratory values [hemoglobin (Hb), thrombocytes, INR, base excess (BE)], computed tomography (CT) imaging, intubation timing, surgery, and volume/transfusion status. ICU data comprised admission lab values, presence and type of organ failure, mechanical ventilation duration, and ICU length of stay. The total hospital stay and mortality were recorded as outcomes.

Statistical analysis was performed using SPSS Version 29 (IBM Inc., Armonk, NY, USA). Absolute and relative frequencies, means, medians, and standard deviations were calculated. For the purpose of group comparisons, a chi-squared test was

applied for categorical data, and a one-way analysis of variance (ANOVA) or Kruskal–Wallis test was applied for metric data, depending on the distribution. In addition, a chi-squared test for linear trend was applied for selected categorical data. Statistical significance was considered if $p < 0.05$. A formal *a priori* sample size or power calculation was not performed because this was a retrospective analysis of all eligible cases available in the registry during the study period.

Where ordinal trends were observed across BMI categories (e.g., linear increase or decrease), a linear trend test (p lin.) was performed. In instances where non-linear distributions were observed, a series of comparisons between BMI groups were conducted to identify specific differences.

Given the matched 1:2:1 set design, the primary analytical strategy was to compare outcomes across BMI strata within matched sets rather than to fit additional high-dimensional multivariable regression models. The number of events, particularly in the underweight and obese groups and in the polytrauma subgroup, would not have supported stable estimates for models including a large number of covariates without risking overfitting. The primary objective of the study was therefore descriptive and comparative, with the aim of characterizing patterns of organ failure, length of stay, and mortality across BMI categories under closely matched injury severity and treatment patterns, rather than developing fully adjusted causal models.

The definition of organ failure was determined by the Sepsis-related Organ Failure Assessment (SOFA) score, with a score >2 being sustained over a period of at least two days. MOF was defined as the simultaneous failure of ≥ 2 or more organ systems for a period of two days or more. Sepsis was identified by the presence of Systemic Inflammatory Response Syndrome (SIRS) criteria in combination with microbial confirmation.

3 Results

3.1 Demographic data

Unless stated otherwise, the ensuing results pertain to the aggregate cohort of 5,766 ICU-admitted trauma patients. The results of the matched cohort ($n = 768$) are explicitly labelled as such.

The mean age in the total cohort was found to be lowest in the underweight group, at 35 years, and highest in the obese group, at 49 years. The demographic profile of the patient population is characterized by a predominance of males, with a male proportion of 76.4%.

The mean height was recorded as 176 cm, with no statistically significant differences observed between BMI groups. Conversely, there was a marked variation in body weight and BMI across the groups. The mean body weight was found to be 80.2 kg overall, with group-specific values of 55.0 kg (Group I), 77.6 kg (Group II), and 105.2 kg (Group III). Consequently, the mean BMI was 25.8 kg/m² overall, and 18.7 kg/m², 24.9 kg/m², and 34.4 kg/m² in Groups I, II, and III, respectively. The demographic data of

the total cohort are presented in Table 1, and those of the matched cohort in Table 2. Within the matched cohort (see Table 2), the BMI groups were, by design, identical with respect to the matching variables (age categories, sex, injury pattern, and type of treatment), reflecting the exact matching procedure.

TABLE 1 Overview of the demographic data of the overall cohort.

Variables	Underweight $n = 248$	Normal $n = 4,722$	Obese $n = 760$	Total
Height (cm)	171 (9)	177 (8)	175 (9)	176 (8)
Weight (kg)	55.0 (6.8)	77.6 (10.5)	105.2 (17.0)	80.2 (15.8)
BMI (kg/m ²)	18.7 (1.2)	24.9 (2.4)	34.4 (4.9)	25.8 (4.6)
Age (years)	35.0 (20.2)	43.2 (19.2)	49.1 (16.9)	43.6 (19.1)
Age 50+ years (%)	18.3	34.3	48.8	35.5
Male (%)	39.8	78.9	76.7	76.4
Female (%)	60.2	21.1	23.3	23.6

Continuous variables are presented as mean (standard deviation). Categorical variables are presented as percentages.

Cm, centimeter; kg, kilogram; BMI, body mass index; m², square meter.

TABLE 2 Overview of the demographic data of the matched sets.

Variables	Underweight $n = 192$	Normal $n = 384$	Obese $n = 192$
Height (cm)	172 (10)	174 (9)	173 (9)
Weight (kg)	55.8 (7.1)	74.5 (9.9)	106.9 (18.4)
BMI (kg/m ²)	18.7 (1.2)	24.5 (1.9)	35.7 (5.1)
Age (Years)	39.9 (22.3)	40.6 (20.6)	40.5 (19.9)
^a Age 50+ years (%)	27.1	27.1	27.1
^a Male (%)	53.6	53.6	53.6
^a Female (%)	46.4	46.4	46.4
Pre-existing disease (%)	37.0	28.9	41.1
Injury pattern (AIS 3+):			
^a Head (%)	38.0	38.0	38.0
^a Thorax (%)	40.6	40.6	40.6
^a Abdomen (%)	18.2	18.2	18.2
^a Extremities (%)	49.0	49.0	40.0
ISS	21.1 (10.5)	23.0 (12.5)	22.1 (11.1)
ISS 16+ (%)	63.5	69.3	69.3
^a Surgery performed (%)	93.2	93.2	93.2
Invasive ventilation (%)	60.9	66.1	72.9
MOF (%)	19.3	21.1	28.6
Sepsis (%)	6.3	7.3	11.5
Hospital mortality (%)	5.2	5.7	10.4
Non-survivor N	10	22	20
Mean days to death	7.9	4.6	14.7
Survivor N	182	362	172
Days of invasive Ventilation ^b	1 (0–4) mean 4.2	1 (0–7) mean 5.8	2 (0–6) mean 5.7
Days on ICU ^b	5 (2–13) mean 9.1	5.5 (3–14) mean 10.2	6 (2–14) mean 11.4
Days in hospital ^b	21 (13–37) mean 26.0	23 (14–37) mean 29.1	26 (15–41) mean 31.4

Continuous variables are presented as mean (standard deviation). Categorical variables are presented as percentages.

cm, centimeter; kg, kilogram; BMI, body mass index; m², square meter; ISS, Injury Severity Score; AIS, abbreviated injury scale; MOF, multiple organ failure.

^aMatching criteria.

^bSurvivor only.

3.2 Injury pattern

In the total cohort, serious head injuries occurred in 44.8% of patients, thoracic injuries in 50.0%, abdominal injuries in 19.4%, and extremity injuries in 41.3% of patients. Surgical intervention was necessary in 89% of cases.

The mean Injury Severity Score (ISS) was 24.3 (SD 12.4) in the total cohort, with no significant difference between BMI groups ($p = 0.143$).

3.3 Pre-existing conditions

In the total cohort, 33.4% of patients had pre-existing conditions, with significantly higher rates observed in the underweight (32.9%) and obese (48.4%) groups compared to the normal-weight group (30.7%). Subsequent pairwise analyses revealed that the overweight group differed significantly from both other groups, whereas no significant difference was found between Group I and Group II ($p = 0.55$).

3.4 Accident mechanism

Traffic accidents were the most prevalent cause of admission, accounting for 66.3% of cases. The frequency of these incidents increased in accordance with BMI, with 59.4% of cases occurring in the underweight group, 66.0% in the normal-/overweight group, and 73.8% in the obese group. The mechanisms of accidents exhibited variation according to BMI group: Patients with a BMI under 20 kg/m² were more often injured as pedestrians, cyclists, or through falls (low and high). Conversely, obese patients were predominantly implicated in automobile accidents. All results on accident mechanism are shown in Table 3. The mean rescue time from accident to hospital arrival was 78.2 ± 41.9 min, with no significant differences between groups in the total cohort. No significant group differences were found in terms of pre-hospital shock symptoms or the need for catecholamine administration.

3.5 Emergency room management

In the total cohort, 22.8% of patients were pre-hospital intubated, with similar rates observed across BMI groups (Group I: 25.0%, II: 21.7%, III: 22.8%). Emergency room intubation was performed in

45.3% of all cases, more frequently in normal/overweight (48.2%) and obese (47.3%) patients than in underweight patients (37.5%), though the difference was not statistically significant. Furthermore, 33.0% of patients were not intubated (Group I: 37.5%, II: 30.1%, III: 29.9%).

The utilization of whole-body CT revealed no substantial discrepancy in the total cohort.

The mean number of diagnoses was 5.5 ± 3.1 in the total cohort with no statistical significance.

3.6 Emergency room admission laboratory

In the total cohort, no clinically relevant differences were observed in the shock room admission laboratory values across BMI groups. Although the Quick's value demonstrated a statistically significant difference ($p = 0.002$), all other values remained within the normal reference range (>70%) and lacked clinical relevance. All results are presented in Table 4.

3.7 (multi-) organ failure

The study observed a failure of at least one organ system in 40.5% of patients, with a significant linear increase across BMI categories ($p = 0.011$, p lin. = 0.005). The prevalence of multiple organ failure was 26.3% overall, with a demonstrable trend toward higher prevalence in obese patients. A number of significant differences were identified, particularly in cases of cardiovascular failure ($p = 0.001$, p lin. = 0.002) and pulmonary failure exhibited a linear trend (p lin. = 0.019), both showing a significant linear increase with rising BMI. The remaining results are presented in Table 4. Figure 1 presents the proportion of individual organ systems with (multi-) organ failure in the total cohort.

3.8 Intensive care unit admission laboratory

In the total cohort, statistically significant differences were observed in ICU admission laboratory values across BMI groups. Hemoglobin, Quick and Base excess level showed significant differences. However, these are likely attributable to the large sample size, as all values remained within the reference range and lacked clinical relevance. Full results are presented in Table 4.

TABLE 3 Detailed presentation of the various accident mechanisms in the overall cohort.

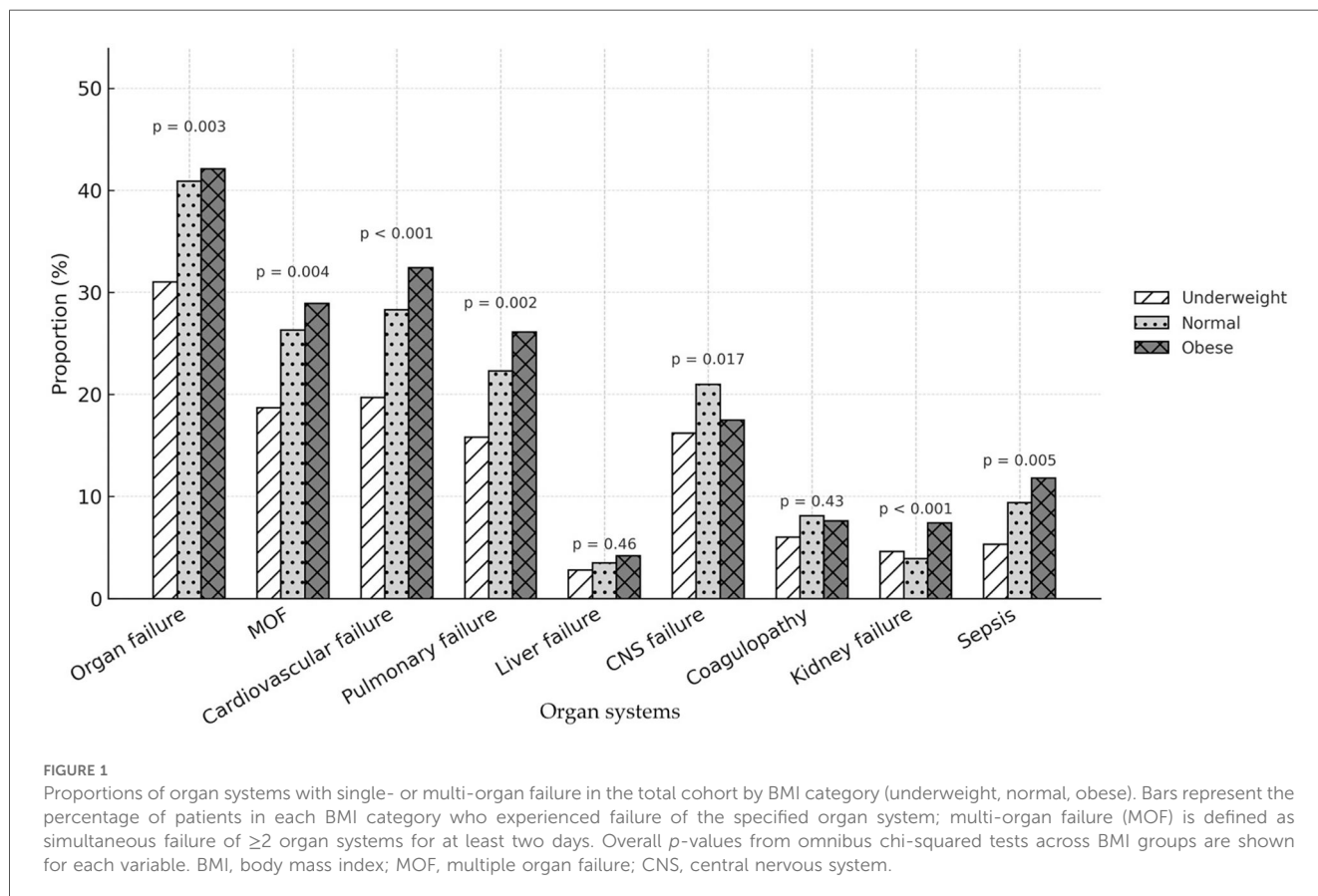
Variables	Underweight	Normal	Obese	Total	p -value	p -value lin.
Car %	33.2	37.7	49.2	39.4	0.004	0.002
Motorcycle %	7.5	15.8	14.4	13.4	0.022	0.048
Bicycle %	8.0	5.3	4.3	5.7	0.267	0.12
Pedestrian %	10.7	7.2	5.9	7.8	0.189	0.082
Fall > 3 m %	19.3	16.8	10.7	15.9	0.061	0.024
Fall < 3 m %	13.4	8.8	8.0	9.8	0.151	0.082
Other %	8.0	8.3	7.5	8.0		

Continuous variables are presented as mean (standard deviation). Categorical variables are presented as percentages. lin., linear; m, meter.

TABLE 4 Detailed presentation of the (multi-)organ failure, emergency room admission laboratory and intensive care admission laboratory in the overall cohort.

Variables	Underweight	Normal	Obese	Total	p-value	P for trend
Organ failure %	31.0	40.9	42.1	40.5	0.003	0.012
MOF %	18.7	26.3	28.9	26.3	0.004	0.003
Cardiovascular failure %	19.7	28.3	32.4	28.4	<0.001	<0.001
Pulmonary failure %	15.8	22.3	26.1	22.5	0.002	<0.001
Liver failure %	2.8	3.5	4.2	3.5	0.46	0.22
CNS failure %	16.2	21.0	17.5	20.3	0.017	0.45
Coagulopathy %	6.0	8.1	7.6	7.9	0.43	0.69
Kidney failure %	4.6	3.9	7.4	4.4	<0.001	<0.001
Sepsis %	5.3	9.4	11.8	9.6	0.005	0.002
Hemoglobin (Hb) (g/dL) ER	11.3	11.8	12.1	11.8	<0.001	
Thrombocytes (/nL) ER	213	205	215	206	0.002	
Quick (%) ER	78	81	86	82	<0.001	
BE (mmol/L) ER	-2.9	-2.7	-2.7	-2.7	0.89	
Hemoglobin (Hb) (g/dL) ICU	10.2	10.8	11.1	10.8	<0.001	
Thrombocytes (/nL) ICU	171	166	176	167	0.005	
Quick (%) ICU	73	78	83	79	<0.001	
BE (mmol/L) ICU	-1.9	-1.7	-1.9	-1.7	0.50	

Continuous variables are presented as mean (standard deviation). Categorical variables are presented as percentages. lin., linear; m, meter; MOF, multiorgan failure; ER, emergency room; ICU, intensive care unit.



3.9 Mortality

In the total cohort, mortality was lowest in normal/overweight patients (7.1%) and highest in obese patients (9.5%), with

underweight at 8.0%. While the overall comparison was not statistically significant, the linear trend was significant (p in. = 0.025), indicating a continuous increase in mortality across BMI groups. Early mortality (within 24 h) showed no significant differences.

3.10. Outcome

In the overall cohort, obese patients exhibited the longest durations of invasive ventilation, ICU stay, and hospitalization, whereas underweight patients demonstrated the shortest. Differences were highly statistically significant for ventilation ($p < 0.001$), hospital stay ($p < 0.001$) and for ICU stay ($p < 0.001$). The complete range of outcomes is presented in Table 5. The outcome variables for the survivors in the matched sets are presented in Figure 2. Among patients who died during their hospitalization, obese individuals also demonstrated significant longer durations compared to underweight patients (ventilation: $p = 0.014$; ICU: $p = 0.004$; hospital stay: $p = 0.004$).

3.11. Polytrauma subgroup of the matched cohort

In the polytrauma subgroup of the matched cohort the injury severity was markedly elevated (mean ISS = 32.7), without significant variation across BMI categories ($p = 0.294$). Patients with obesity were found to have a higher prevalence of

comorbidities in comparison to those with a normal or overweight BMI (37.7% vs. 26.1% in underweight and normal) but the overall comparison was not significant ($p = 0.185$).

The outcome analysis demonstrated a non-significant tendency towards elevated mortality in obese patients (15.9% vs. 9.4% and 8.7%, $p = 0.291$). The ICU stay was found to be not significant prolonged in patients categorized as obese in comparison to those with a BMI classified as normal/overweight (13 vs. 10 and 9 days; $p = 0.134$). The hospital stay showed no statistical difference ($p = 0.969$).

Pulmonary failure did not differ by BMI ($p = 0.755$) and MOF showed no significant difference ($p = 0.217$), whereas cardiovascular failure was significantly more common in obese patients (50.7%; $p = 0.017$). Table 6 shows the complete data of the polytrauma subgroup.

4 Discussion

This study examined the impact of BMI on the outcomes of intensive care for patients with trauma, utilizing data from the TraumaRegister DGU®. A predefined subgroup analysis focused

TABLE 5 Duration of treatment in survivors in the total cohort ($n = 5,319$).

Variables	Underweight $n = 261$	Normal $n = 4,370$	Obese $N = 688$	<i>P</i> value
Days of invasive ventilation	1 (0–4)	2 (0–10)	2 (0–12)	<0.001
Days on the intensive care unit	5 (2–11)	7 (3–17)	8 (3–19)	<0.001
Length of stay in hospital (days)	20 (12–32)	23 (14–36)	27 (15–43)	<0.001

Data are given as median (interquartile ranges); Kruskal–Wallis test.

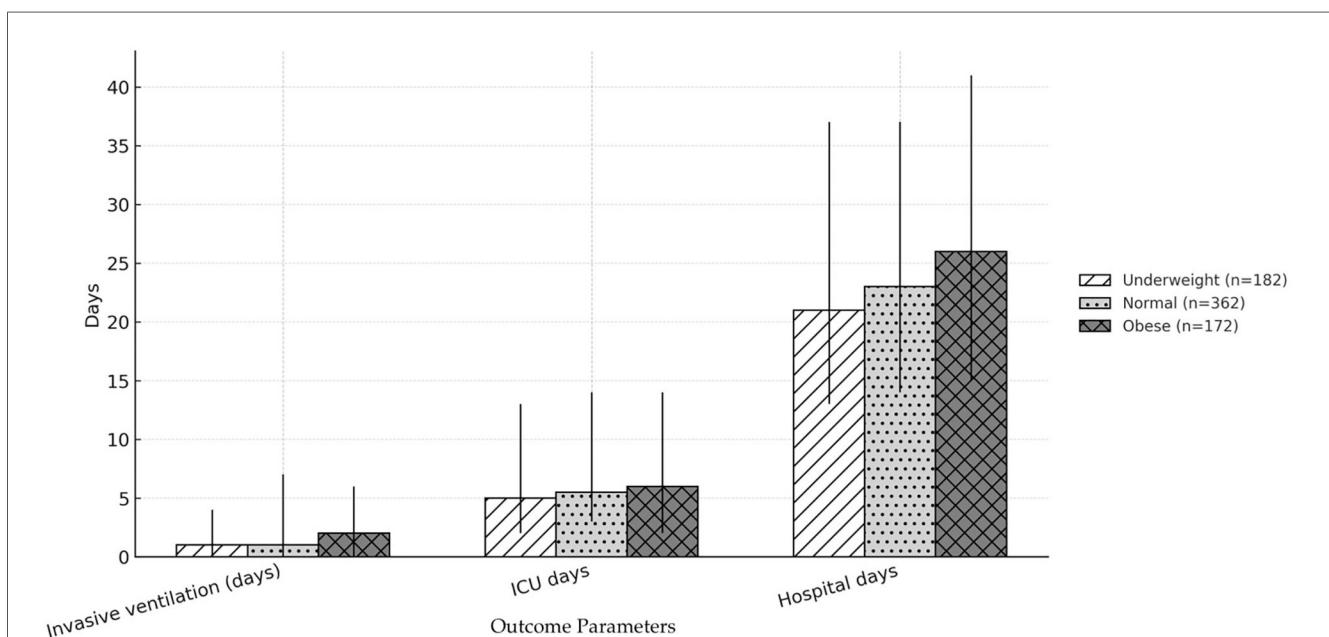


FIGURE 2

Outcome parameters among the survivors in the matched sets (invasive ventilation, ICU days, hospital days): duration of invasive ventilation, ICU length of stay, and total hospital length of stay. Data are presented as medians with interquartile ranges (IQR). BMI, body mass index; ICU, intensive care unit.

TABLE 6 Detailed data of the polytrauma subgroup from the matched cohort.

Variables	Underweight <i>n</i> = 69	Normal <i>n</i> = 138	Obese <i>n</i> = 69	Total <i>n</i> = 276	<i>P</i> value
Age (years)	35.2 (17.5)	37.3 (17.5)	37.1 (16.6)	36.7 (17.2)	0.684
BMI (kg/m ²)	18.8 (1.0)	24.3 (1.7)	36.5 (5.3)	25.9 (7.1)	—
Injury severity score	31.3 (8.9)	33.8 (12.2)	32.1 (11.3)	32.7 (11.2)	0.294
Comorbidities %	26.1	26.1	37.7	29.0	0.185
Ventilation (days)	5 (1–12)	3 (1–14)	6 (2–16)	5 (1–15)	0.219
ICU Stay (days)	10 (5–22)	9 (4–19)	13 (7–22)	11 (5–21)	0.134
Hospital Stay (days)	29 (15–44)	28 (16–49)	28 (19–43)	28 (16–45)	0.969
Pulmonary failure %	27.5	31.2	33.3	30.8	0.755
Cardiovascular failure %	37.7	30.4	50.7	37.3	0.017
MOF %	36.2	34.1	46.4	37.7	0.217
Mortality %	8.7	9.4	15.9	10.9	0.291

Continuous variables are presented as mean (standard deviation). Categorical variables are presented as *n* (%).

on patients with polytrauma. The findings of the study indicate that an increased BMI is associated with a higher incidence of organ failure, as well as prolonged mechanical ventilation, ICU stay, and total hospital stay. Furthermore, increasing BMI was significant associated with higher mortality.

Contrary to the hypothesis posited by the so-called “obesity paradox”, which suggests an increased likelihood of survival and a protective effect for increased body weight in critically ill patients, the findings of the present study do not provide support for a survival benefit of higher BMI in severely injured ICU patients. While previous studies - particularly in intensive care settings - have reported a survival benefit in obese individuals, potentially due to greater metabolic reserves stored as increased fat tissue (9, 13, 31) or immunomodulatory effects (13, 32, 33), this analysis offers opposing findings. The present results are in alignment with those of recent studies that have called into question the so-called “obesity paradox” and have highlighted methodological biases such as selection effects and inadequate adjustment for comorbidities (17, 28, 29, 34, 35). In polytrauma patients, whose outcomes depend heavily on respiratory and cardiovascular stability, the physiological disadvantages of obesity may outweigh any potential benefits (36). The elevated prevalence of cardiovascular and pulmonary organ failure and mortality in obese patients in this study supports this hypothesis.

These observations corroborate earlier studies that obesity has been associated with impaired respiratory mechanics, systemic inflammation, and altered cardiovascular responses in critically ill patients (17, 37). In the context of trauma care, these pathophysiological changes may translate into a higher vulnerability to MOFs and a more complicated ICU stay (17). Consequently, BMI should not be regarded in isolation but should be considered alongside comorbidities, functional status, and inflammatory profiles, since those factors may influence the outcome as well (5–7). In view of the findings, which are not consistent with a protective “obesity paradox” in this setting, there is a need to re-evaluate the suggested beneficial effects of excess body weight in trauma and intensive care. Contrary to the assumption of a general survival advantage in obese patients, the results of this study support a more nuanced perspective.

This perspective considers BMI as one of several interrelated risk markers, alongside comorbidities, functional status, and inflammatory profiles.

Previous studies are consistent with this research, indicating that overweight and obese patients often require more intensive and prolonged care in the ICU. Numerous studies have documented a positive correlation between elevated BMI and the duration of mechanical ventilation, as well as extended ICU and hospital stays, particularly in trauma patients (38, 39). Reduced lung compliance in obese patients has been demonstrated to result in an increased susceptibility to respiratory infections (38, 39). Furthermore, these patients have also been shown to be more susceptible to urinary tract infections (38) and impaired mobilization (20, 36). Consequently, these factors may contribute to prolonged ICU stays in obese trauma patients (38). This phenomenon is further exacerbated in polytraumatized patients (36). The prolonged ventilation and ICU stays observed in the present cohort are consistent with the mounting evidence suggesting that excess body mass can adversely affect critical care trajectories (39).

This study suggests that excess weight may increase the risk of in-hospital mortality. While early mortality (within 24 h) did not demonstrate a significant difference between BMI categories, a positive linear correlation was observed between BMI and overall mortality. It is hypothesized that excess weight may have a detrimental effect on outcomes during the subacute and recovery phases. This may be attributable to complications such as infection, immobility, or organ dysfunction (36). The mortality rate among obese patients was found to be more than double that of underweight individuals in this study. This finding is consistent with the results of earlier studies, which reported an obesity-related mortality rate that was 2.89 times higher among critical care patients (40).

Conversely, underweight patients exhibited reduced ventilation times, ICU stays, and total hospital stays among survivors, despite an elevated prevalence of pre-existing conditions. These observations may imply enhanced physiological recuperation, at least among survivors of the primary trauma. However, it must be acknowledged that underweight patients have been shown in other studies to suffer

from early mortality due to limited physiological reserves and malnutrition (18, 21–24). In the present study, the early mortality of underweight patients was not found to be significantly higher than in the other groups, but this finding is based on relatively small numbers and limited statistical power. Moreover, shorter ICU and ventilation durations among underweight survivors may be partly driven by survivor bias: particularly frail underweight patients may die early and are therefore not represented in the group of survivors with longer ICU courses. Our analyses cannot disentangle whether the observed shorter stays in survivors reflect genuine physiological advantages in this subgroup or selective survival of the fittest underweight patients. These findings should therefore be interpreted as descriptive and hypothesis-generating rather than as evidence of a protective effect of underweight.

Consequently, alternative explanations for our findings deserve consideration. Firstly, the observed associations may have been influenced by residual confounding from comorbidities, metabolic health, or frailty, which were not fully captured in the registry. Secondly, survivorship bias may influence comparisons across BMI groups. For example, if particularly vulnerable obese or underweight patients die early and are therefore underrepresented among survivors with prolonged ICU courses, this may introduce a bias in the results. The observational design of the study does not permit the full disentangling of these mechanisms, and therefore the associations observed should be interpreted with caution.

The present study has been distinguished by its use of a matched 1:2:1 set design. Such an approach has been identified as an effective method of minimizing the impact of confounding variables such as age, sex, and injury pattern. This methodological approach facilitated a more balanced comparison between BMI groups. However, it is important to acknowledge the limitations of the study. The retrospective nature of the study, in conjunction with the reliance on registry data, imposes constraints on the available information concerning important covariates, including smoking status, physical activity levels, and precise body composition metrics. Additionally, BMI does not account for differences in muscle mass or fat distribution, which can significantly affect patient outcomes. Moreover, there was a paucity of data regarding frailty status, sarcopenia, nutritional indices, and detailed metabolic comorbidities such as diabetes, dyslipidaemia, or non-alcoholic fatty liver disease. These factors are closely related to both BMI and outcome and may represent important sources of unmeasured or incompletely measured confounding. Consequently, the observed associations between BMI, organ failure, and mortality should be interpreted as adjusted only for the variables included in the matching procedure. Therefore, causal inferences regarding the independent effect of BMI are not warranted.

Furthermore, the study period (2005–2009) preceded several advances in trauma systems and critical care, including wider implementation of damage-control resuscitation, refined transfusion practices, and protocolized ICU management. These developments may have resulted in a decline in the absolute

risks of organ failure and mortality in more recent cohorts. However, we consider it plausible that the qualitative pattern of associations between BMI and outcome remains broadly comparable, and our results should therefore be interpreted as reflecting the relationship between BMI and intensive care trajectories in the context of trauma care during that time period. Consequently, it is recommended that future studies consider the incorporation of alternative anthropometric measures, such as waist-to-hip or waist-to-height ratios. This would provide a more comprehensive assessment of obesity-related risk and inflammatory status. This would improve risk stratification and guide personalized intensive care interventions.

Despite the multicenter study design, the generalizability of these results to other health systems and age groups is questionable and requires further investigation. In addition, only those TR-DGU[®] cases with documented height and weight between 2005 and 2009 were eligible for inclusion. The resulting cohort may therefore not be fully representative of the broader and more contemporary TR-DGU[®] trauma population, in which injury mechanisms, case mix, and ICU organization may differ.

WHO cut-offs were not used in primary analyses due to sparse strata at the extremes, particularly among underweight and morbidly obese patients. This approach was deemed to be unfeasible, as it would have resulted in unstable estimates. Conversely, a more inclusive approach was adopted, encompassing a wider range of BMI categories to ensure sufficient sample sizes within each group. It is recommended that future work, or additional sensitivity analyses applying the WHO categories, be conducted using larger or more recent datasets. This will assist in further assessing the robustness of these findings across alternative BMI definitions.

Finally, multivariable regression analyses were not performed beyond the matching variables; therefore, residual confounding by covariates not included in the matching algorithm cannot be excluded. Furthermore, despite the fact that our matching strategy led to a substantial reduction in variations with regard to age, sex, injury pattern, and treatment modality, it did not explicitly account for all comorbidities or physiological risk factors. It is therefore hypothesized that residual imbalances in comorbidity profiles and other unmeasured baseline characteristics may still influence mortality and organ failure outcomes across BMI groups. Furthermore, the calculation of standardized mean differences was not performed, the exact matching algorithm ensured perfect balance of the predefined matching variables across BMI groups in the matched cohort. Residual differences may persist for covariates that were not explicitly included in the matching procedure, and these are acknowledged as potential sources of remaining confounding.

In view of the established correlation between elevated BMI and adverse outcomes, including prolonged ICU stay, organ failure, and increased mortality, it is recommended that obese trauma patients be designated a high-risk category requiring more intensive monitoring and individualized care. Early respiratory support, infection prevention, mobilization strategies,

and hemodynamic surveillance are all crucial areas in which particular attention should be paid. Concomitantly, the findings highlight the need to move beyond BMI as a sole determinant of clinical assessments, emphasizing the integration of functional and metabolic parameters into the triage and care planning processes within the ICU. The introduction of BMI-adjusted early warning scores and targeted respiratory and cardiovascular support bundles for obese trauma patients may be a useful addition to current clinical practice.

5 Conclusion

In conclusion, the present study demonstrates that an increased BMI is associated with poorer outcomes in trauma patients requiring intensive care. Patients with a BMI categorized as obese have been observed to experience elevated rates of organ failure, prolonged ICU stays and increased mortality. Conversely, patients with a BMI categorized as underweight may benefit from a reduced duration of ICU treatment among survivors. Taken together, these findings are not consistent with a protective “obesity paradox” in the context of trauma care and underscore the need for individualized ICU strategies that incorporate functional and metabolic risk profiles.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: the dataset used in this study is not publicly available. The data are proprietary to the Akademie der Unfallchirurgie (AUC) GmbH as part of the TraumaRegister DGU® and can only be accessed upon request to the registry holder, subject to approval, data use agreements, and applicable data protection regulations. The authors are therefore not permitted to share the raw data directly. Requests to access these datasets should be directed to mark.gerbershagen@uni-wh.de.

Ethics statement

The studies involving humans were approved by Ethics Committee of the University Witten/Herdecke (No. 64/2018). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants’ legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

TS: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. NS: Conceptualization, Data curation, Formal analysis, Validation, Writing – original draft, Writing – review & editing. AB: Conceptualization, Data curation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. RL: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Writing – original draft, Writing – review & editing. MG: Conceptualization, Data curation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

Funding

The author(s) declared that financial support was not received for this work and/or its publication.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was used in the creation of this manuscript. The authors verify and take full responsibility for the use of generative AI in the preparation of this manuscript. DeepL was used exclusively for text improvement and was not employed to generate, analyze, or interpret any scientific content, data, or conclusions.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher’s note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

- World Health Organisation [WHO]. Obesity and overweight (2022). <https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight> (Accessed April 8, 2025).
- Statistisches Bundesamt. Frauen und Männer mit Übergewicht/Adipositas. Stat Bundesamt (2021). <https://www.destatis.de/DE/Themen/Querschnitt/Gleichstellungen/indikatoren/adipositas-f23.html> (Accessed April 8, 2025).
- Deutsche Adipositas Gesellschaft. Interdisziplinäre Leitlinie der Qualität S3 zur 'Prävention und Therapie der Adipositas' (2014).
- World Health Organisation [WHO]. Body mass index (BMI) (2004). <https://www.who.int/data/gho/data/themes/topics/topic-details/GHO/body-mass-index> (Accessed April 8, 2025).
- Nuttall FQ. Body mass Index: obesity, BMI, and health: a critical review. *Nutr Today*. (2015) 50:117–28. doi: 10.1097/NT.0000000000000092
- Bray GA. Beyond BMI. *Nutrients*. (2023) 15(10):2254. doi: 10.3390/nu15102254
- Jeong SM, Lee DH, Rezende LFM, Giovannucci EL. Different correlation of body mass index with body fatness and obesity-related biomarker according to age, sex and race-ethnicity. *Sci Rep*. (2023) 13(1):3472. doi: 10.1038/s41598-023-30527-w
- Shuey MM, Huang S, Levinson RT, Farber-Eger E, Cahill KN, Beckman JA, et al. Exploration of an alternative to body mass index to characterize the relationship between height and weight for prediction of metabolic phenotypes and cardiovascular outcomes. *Obes Sci Pract*. (2021) 8(1):124–30. doi: 10.1002/osp4.543
- Yeo HJ, Kim HL, So MW, Park JM, Kim D, Cho WH. Obesity paradox of sepsis in long-term outcome: the differential effect of body composition. *Intensive Crit Care Nurs*. (2025) 87:103893. doi: 10.1016/j.iccn.2024.103893
- Horwich TB, Fonarow GC, Clark AL. Obesity and the obesity paradox in heart failure. *Update Obes Cardiovasc Dis*. (2018) 61:151–6. doi: 10.1016/j.pcad.2018.05.005
- Dvorak JE, Lester ELW, Maluso PJ, Tatebe L, Schlanser V, Kaminsky M, et al. The obesity paradox in the trauma patient: normal may not be better. *World J Surg*. (2020) 44(6):1817–23. doi: 10.1007/s00268-020-05398-1
- Khatua B, El-Kurdi B, Patel K, Rood C, Noel P, Crowell M, et al. Adipose saturation reduces lipotoxic systemic inflammation and explains the obesity paradox. *Sci Adv*. (2021) 7(5):eabd6449. doi: 10.1126/sciadv.abd6449
- Karampela I, Chrysanthopoulou E, Christodoulatos GS, Dalamaga M. Is there an obesity paradox in critical illness? Epidemiologic and metabolic considerations. *Curr Obes Rep*. (2020) 9(3):231–44. doi: 10.1007/s13679-020-00394-x
- Zhang T, Krekels EHJ, Smit C, Knibbe CAJ. Drug pharmacokinetics in the obese population: challenging common assumptions on predictors of obesity-related parameter changes. *Expert Opin Drug Metab Toxicol*. (2022) 18(10):657–74. doi: 10.1080/17425255.2022.2132931
- Smit C, Hoogd SD, Bruggemann RJM, Knibbe CAJ. Obesity and drug pharmacology: a review of the influence of obesity on pharmacokinetic and pharmacodynamic parameters. *Expert Opin Drug Metab Toxicol*. (2018) 14(3):275–85. doi: 10.1080/17425255.2018.1440287
- Drury B, Kocharians C, Dong F, Tran L, Beroukhim S, Hajjafar R, et al. Impact of obesity on mortality in adult trauma patients. *Cureus*. (2021) 13(2):e13352. doi: 10.7759/cureus.13352
- Cromwell PM, Reynolds IS, Heneghan HM, Glasgow SM. Obesity and outcomes in trauma - a systematic review and meta-analysis. *Injury*. (2023) 54(2):469–80. doi: 10.1016/j.injury.2022.10.026
- Yu W, Jiang W, Yuan J, Fan T, Xiao H, Sun L, et al. Association between BMI and outcomes in critically ill patients: an analysis of the MIMIC-III database. *Sci Rep*. (2024) 14(1):31127. doi: 10.1038/s41598-024-82424-5
- Carpenter AM, Neal DW, Johnson-Mann CN, Taylor JE. Obesity associated with increased mortality and hospital length of stay in trauma laparotomy patients. *Am Surg*. (2023) 89(7):3306–8. doi: 10.1177/00031348231160850
- Hatchimonji JS, Kaufman EJ, Vasquez CR, Shashaty MGS, Martin ND, Holena DN. Obesity is associated with mortality and complications after trauma: a state-wide cohort study. *J Surg Res*. (2020) 247:14–20. doi: 10.1016/j.jss.2019.10.047
- Ayalon I, Woo JG, Basu RK, Kaddourah A, Goldstein SL, Kaplan JM. Weight as a risk factor for mortality in critically ill patients. *Pediatrics*. (2020) 146(2):e20192829. doi: 10.1542/peds.2019-2829
- Chen M-Y, Yang Y-J. Being underweight is an independent risk factor for poor outcomes among acutely critically ill children. *Nutr Clin Pract*. (2018) 33:433–8. doi: 10.1177/0884533617712225
- Choi J, Smiley A, Latifi R, Gogna S, Prabhakaran K, Con J, et al. Body mass Index and mortality in blunt trauma: the right BMI can be protective. *Am J Surg*. (2020) 220(6):1475–9. doi: 10.1016/j.amjsurg.2020.10.017
- Wier J, Firoozabadi R, Duong A, Patterson JT. Underweight patients experience higher inpatient complication and mortality rates following acetabular fracture. *Eur J Orthop Surg Traumatol*. (2024) 34(7):3543–51. doi: 10.1007/s00590-023-03739-z
- Vorbeck J, Bachmann M, Dusing H, Hartensuer R. Mortality risk factors of severely injured polytrauma patients (prehospital mortality prediction score). *J Clin Med*. (2023) 12(14):4724. doi: 10.3390/jcm12144724
- Iyengar KP, Venkatesan AS, Jain VK, Shashidhara MK, Elbana H, Botchu R. Risks in the management of polytrauma patients: clinical insights. *Orthop Res Rev*. (2023) 15:27–38. doi: 10.2147/ORR.S340532
- Peters U, Dixon AE. The effect of obesity on lung function. *Expert Rev Respir Med*. (2018) 12:755–67. doi: 10.1080/17476348.2018.1506331
- Oga EA, Eseyin OR. The obesity paradox and heart failure: a systematic review of a decade of evidence. *J Obes*. (2016) 2016:9040248. doi: 10.1155/2016/9040248
- Atkins K, Cairns B, Schneider A, Charles A. An evaluation of the "obesity paradox" in isolated blunt abdominal trauma in the United States. *Injury*. (2024) 55(7):111612. doi: 10.1016/j.injury.2024.111612
- Lechi A. The obesity paradox: is it really a paradox? Hypertension. *Eat Weight Disord - Stud Anorex Bulim Obes*. (2017) 22:43–8. doi: 10.1007/s40519-016-0330-4
- Cheng FW, Gao X, Mitchell DC, Wood C, Rolston DDK, Still CD, et al. Metabolic health status and the obesity paradox in older adults. *J Nutr Gerontol Geriatr*. (2016) 35(3):161–76. doi: 10.1080/21551197.2016.1199004
- Ludwig N, Hurt RT, Miller KR. The obesity paradox: validity and clinical implications. *Curr Pulmonol Rep*. (2017) 6:58–63. doi: 10.1007/s13665-017-0167-y
- Karampela I, Christodoulatos GS, Dalamaga M. The role of adipose tissue and adipokines in sepsis: inflammatory and metabolic considerations, and the obesity paradox. *Curr Obes Rep*. (2019) 8:434–57. doi: 10.1007/s13679-019-00360-2
- Amin RM, Raad M, Rao SS, Musharbash F, Best MJ, Amanatullah DF. Survival bias may explain the appearance of the obesity paradox in hip fracture patients. *Osteoporos Int*. (2021) 32(12):2555–62. doi: 10.1007/s00198-021-06046-7
- Laird BJA, Skipworth RJE. The obesity paradox in cancer: is bigger better? *J Cachexia Sarcopenia Muscle*. (2022) 13:1440–1. doi: 10.1002/jcsm.13007
- Elmhiregh A, Ahmed AF, Dabboussi AM, Ahmed GO, Abdelrahman H, Ibrahim T. The impact of obesity on polytraumatized patients with operatively treated fractures. *Injury*. (2022) 53(7):2519–23. doi: 10.1016/j.injury.2022.03.059
- Anderson MR, Shashaty MGS. Impact of obesity in critical illness. *Chest*. (2021) 160:2135–45. doi: 10.1016/j.chest.2021.08.001
- Bochicchio GV, Joshi M, Bochicchio K, Nehman S, Tracy JK, Scalea TM. Impact of obesity in the critically ill trauma patient: a prospective study. *J Am Coll Surg*. (2006) 203(4):533–8. doi: 10.1016/j.jamcollsurg.2006.07.001
- De Jong A, Wrigge H, Hedenstierna G, Gattinoni L, Chiumello D, Frat JP, et al. How to ventilate obese patients in the ICU. *Intensive Care Med*. (2020) 46(12):2423–35. doi: 10.1007/s00134-020-06286-x
- Laupland KB, Edwards F, Ramanan M, Shekar K, Tabah A. Reconciling the obesity paradox: obese patients suffer the highest critical illness associated mortality rates. *J Crit Care*. (2021) 66:75–7. doi: 10.1016/j.jccr.2021.08.005