Is extreme obesity a risk factor for cardiac surgery?
An analysis of patients with a BMI ≥ 40

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Abstract

Background: The increasing prevalence of obesity is a public health concern and perceived as a potential risk factor in open heart surgery. We critically appraised the literature available regarding postoperative complications in obese patients. **Methods**: A single-center retrospective evaluation of complication rates (1999—2004) in cardiac surgical patients categorized by body mass index (BMI) was conducted. The overall incidence of complications (CX), renal failure (RF), hemodialysis (HD), atrial fibrillation (AF), cardiac arrest (CA), infections (INF), stroke (CVA and TIA), prolonged ventilation (VENT), and pulmonary embolism (PE) were observed. Patients with normal BMI (20—30) served for comparison, obesity and extreme obesity (ExtOb) were defined as BMI 30—40 and ≥40, respectively. **Results**: In our institutional review of 1920 patients, 1780 met the inclusion criteria with BMI < 20 (n = 53), 20—30 (n = 1056), 30—40 (n = 592), and ≥40 (n = 79) based on National Health and Nutrition Examination Survey (NHANES) criteria. Significant increase in complications (STS database guideline definitions) were observed with a BMI ≥ 40, 58% versus 47% (p = 0.04). Extremely obese patients (ExtOb) had increased length of stay (LOS) (11.4 days vs 9.6 days; $p ≤ 0.01$), rate of renal failure (14.3% vs 5%; $p ≤ 0.01$) and prolonged ventilation (39%; p = 0.01) compared to non-obese patients. Extremely obese had no significant increase in hemodialysis (7.3% vs 3.2%; p = 0.11) or stroke (5.2% vs 2.9%; p = 0.29). Obese patients (Ob) had increased LOS (10 days vs 9.6 days; p = 0.04) and prolonged ventilation (28.3% vs 23.5%; p = 0.03). **Conclusions**: Cardiac surgery can be performed without significant increase in perioperative and 30-day mortality in obese and extremely obese patients. Overall complication rates and LOS in patients with BMI ≥ 40 is increased and demands attention. We provide evidence that rates of few specific complications increase with extreme obesity. For risk stratification in the setting of an obesity epidemic, we advocate an interdisciplinary approach in obese patients undergoing elective cardiac surgery.

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Keywords: Risk assessment; Obesity; Cardiac; CABG; Valve

1. Introduction

The prevalence of obesity (Ob) has increased in the United States and most European countries during the last decade and is continuing to rise [1,2]. This has also been the experience in other affluent and developing societies [2]. The International Obesity Task Force, a non-government organization that studies the obesity epidemic, estimates one out of every five people worldwide is overweight or obese. Obesity, defined as a body mass index (BMI) higher than 30, has increased 8% in the United States since 1994 to 30% of the population. This was estimated from the most recent National Health and Nutrition Examination Survey (NHANES) of the Nation Health Centers of Disease Control and Prevention. It has also been estimated that

age-adjusted extreme obesity (ExtOb), defined as a body mass index greater than 40, has increased from 2.9% [NHANES III (1988—1994)] to 4.7% [NHANES continuous (1999—2000)] during the same time period [1]. The costs of disease prevention and medical management of obese patients are of increasing concern for society [1].

Patients undergoing cardiac surgery with excessive body mass index are likely to have other comorbid factors including the five obesity-related illnesses: type II diabetes mellitus, hypertension, hyperlipidemia, stroke, and coronary artery disease [3]. These illnesses account for approximately 85% of the increased health problems and economic burden of obesity [3,4]. Long-term follow-up of the original Framingham cohort revealed that obesity, measured by Metropolitan Relative Weight, was a significant independent predictor of cardiovascular disease (CVD) [5]. In addition to CVD, the risk of ischemic stroke in the obese is twice as high as the normal population. Obesity has also been positively linked to myocardial dysfunction in patients even without coronary

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artery disease. A direct relationship between diastolic dysfunction and systolic impairment has been described in the context of excessive BMI.

There is currently no systematic assessment of the evidence available regarding extremely obese patients and their perioperative risks. Specifically, the scarcity of data regarding the extremely obese patient population in cardiac surgery, as defined by the NHANES criteria, is addressed. Risk stratification and informed consent are the primary motivation to establish patient-associated factors leading to potentially increased morbidity and mortality.

2. Methods

This is a retrospective analysis of 1920 consecutive patients undergoing cardiac surgery at the University of Wisconsin Hospitals and Clinics between January 1, 1999 and May 28, 2004, excluding cardiac transplantation and ventricular assist device (VAD) surgeries.

Preoperative data were collected using the Society of Thoracic Surgery (STS) data criteria; these included: age, gender, height, weight, date of surgery, current smoking habit, diabetes mellitus, hyperlipidemia, hypertension, and preoperative creatinine level in serum. The operative information reviewed included: cross-clamp time, cardio-pulmonary bypass time, the use of an intraaortic balloon pump, blood product use, and postoperative ventilation time. Postoperative information included the overall complication incidence as well as specific adverse events associated with cardiac surgery, including: deep sternal infection, septicemia, presence of a transient ischemic attach (TIA) or cerebral vascular accident (CVA), prolonged ventilation (>24 h), pulmonary embolism (PE), pneumonia, renal failure (RF) with or without dialysis, heart block, cardiac arrest (CA), adverse events related to anticoagulation (DIC and HIT), tamponade, bleeding requiring reoperation, graft occlusion, valvular dysfunction, atrial fibrillation (AF), gastrointestinal complications, information related to total ventilation time, and reoperation for bleeding or non-cardiac reoperations. Furthermore, outcomes of operative death, 30-day mortality, length of stay (LOS), and intensive care unit stay (ICU) were analyzed.

Body mass index which serves as an indirect measure of total body fat, was calculated using the patients height and weight [BMI = weight (pounds)/height (inches)$^2 \times 703$)] or [BMI = kg/m^2] at the time of surgery in accordance to NHANES 1999—2000 criteria. The patients with a normal or overweight BMI (20—30) were defined as the non-obese reference group (NonOb). Obesity was defined as BMI 30—40 and extreme obesity as a BMI ≥ 40 [1]. To define the BMI categories, the range intervals are closed on the left. A patient with a BMI of ≥ 30 but less than 40 is included in the obese group. Patients whose BMI was lower than 20 ($n = 53$) were excluded from the analysis.

2.1. Statistical methods

Continuous variables are presented as mean $\pm$ one standard deviation. Categorical variables are shown as the percentage of the sample in a given category. A Kruskal—Wallis test was used for comparing medians across groups. For

categorical variables, Fisher's exact test was used. For pairwise contrasts between groups, the Wilcoxon rank sum was used for continuous variables and Fisher's exact test for categorical variables. All computed p values are two-sided. In every instance a value of $p < 0.05$ was considered significant. There was no adjustment to the significance level for the number of hypotheses being tested. All computations were performed in R version 1.9.1 for Windows XP (R Development Core Team, 2003).

For the graphic representation of BMI complication rate, the range in BMI (13.14—58.0) was divided into 10 equal-length intervals, closed on the left, as discussed above. The plot excludes the two highest intervals ([48.8, 53.9], [53.9, 59]), since their respective frequencies ($n = 7$ and $n = 2$) were deemed to be too low to produce reliable complication estimates.

The review was selective for publications assessing high BMI (BMI > 27) in context of complications after cardiac surgery. We critically appraised the literature available after systematic searches of the terms: obesity, body mass index, cardiac surgery, CABG, complication rate, valve surgery, mortality, and morbidity. We reviewed all literature available after the following terms searched, but excluded publications pre-1985 to prevent excessive historical bias. Furthermore, studies that did not provide control group or reviews of less than 50 obese patients were excluded. Databases searched for these terms included: Medline, Up to Date, and University of Wisconsin electronic library systems.

3. Results

The patient and treatment characteristics of the study population are detailed in Table 1. Obese patients with BMI 30—40 in our study do not demonstrate an overall increased complication rate (46.8%; $p = 0.8$). However, this group of patients had significantly increased prolonged ventilation times (28.3% vs 23.5%; $p = 0.03$) and length of stay (10.0 vs 9.6; $p = 0.04$) as inpatient when compared with the non-obese reference category (BMI 20—30, see Table 3). No other adverse events were statistically significant in the obese group compared with the non-obese patient group after open heart surgery.

This study found an increase of specific morbidities following cardiac surgery in the extremely obese patient group when compared to the non-obese patient population (58% vs 46%; $p = 0.04$, see Table 3). Prolonged ventilation, defined as intubation for longer than 24 h (39% vs 23.5%; $p = <0.01$), was more frequently observed in this patient group. The incidence of renal failure, as defined by a creatinine in serum rise twice the baseline value and greater than 2.0 mmol/L, was increased significantly in the extremely obese patient group (14.3% vs 5.0%; $p = <0.01$). Length of stay was also increased (11.4 vs 9.6; $p < 0.001$).

The observed perioperative and 30-day mortality was not shown to be increased in the obese group (BMI ≥ 30); nor was it shown to be elevated in the extremely obese patients (BMI ≥ 40) in this retrospective analysis. This corresponds with previous reports of patients undergoing cardiac surgery with elevated BMI (see Table 4). However, the BMI ≥ 40 has not been previously investigated in this context and presents

Table 1
Patient and treatment characteristics stratified by obesity category

Variable	Non-obese, BMI 20–30 (n = 1056)	Obese, BMI 30–40 (n = 592)	Extreme Obese, BMI ≥ 40 (n = 79)	p value (overall)	p value (non-obese vs obese)	p value (non-obese vs extreme obese)
Patient factors						
Age (year ± SD)	62.5 ± 13.9	62.4 ± 11.8	57.4 ± 10.8	**<0.001**	0.427	**<0.001**
Male sex (%)	772 (73.1%)	430 (72.8%)	37 (46.8%)	**<0.001**	0.908	**<0.001**
Weight (kg ± SD)	77.6 ± 11.6	100.1 ± 12.9	124.9 ± 17.4	**<0.001**	**<0.001**	**<0.001**
Height (cm ± SD)	173 ± 9.4	172.3 ± 9.9	168.4 ± 10.0	**<0.001**	0.491	**<0.001**
BMI ± SD	25.8 ± 2.6	33.6 ± 2.6	43.8 ± 3.9	**<0.001**	**<0.001**	**<0.0010**
Current smoker (%)	210 (31.9%)	103 (26.1%)	10 (19.6%)	**0.044**	0.404	0.083
Diabetes (%)	237 (22.4%)	224 (37.9%)	43 (54.4%)	**<0.001**	**<0.001**	**<0.001**
Hypercholesterolemia (%)	629 (59.6%)	408 (69.0%)	57 (72.2%)	**<0.001**	**<0.001**	**0.031**
Hypertension (%)	668 (63.3%)	449 (76.0%)	67 (84.8%)	**<0.001**	**<0.001**	**<0.001**
Last creatinine (mg/dL ± SD)	1.29 ± 1.1	1.32 ± 1.0	1.29 ± 1.0	**0.050**	**0.025**	0.497
Operative details						
CABG	617	370	45			
Valve	377	179	25			
Other	62	43	9			
Cross-clamp time (min)	110.0	102.9	98.9	**0.015**	**0.010**	0.091
Perfusion time (min)	155.5	147.1	139.1	0.076	0.088	0.082
Intra aortic balloon pump	134 (12.7%)	63 (10.7%)	6 (7.6%)	0.238	0.236	0.217
Blood products used	614 (58.2%)	343 (58.0%)	44 (55.7%)	0.910	0.959	0.723
Postoperative ventilation time (h)	31.23	31.42	55.5	**0.019**	0.062	0.082

CABG total = 1045 and valve total = 606, other = 303; SD: standard deviation.

a novel evaluation of clinical data. Although the low BMI group (<20) showed a trend towards increased overall complication rates, it did not prove to be statistically significant when compared to the normal BMI index (p = 0.78).

All other potential cardiac surgical complications evaluated showed no important clinical differences between the BMI categories. This included sepsis, CVA or TIA, pulmonary embolism, arrhythmias, cardiac arrest, atrial fibrillation, or anticoagulation-related complications. The actual frequency of complications and its statistical significance is detailed in Table 2.

In order to provide a graphic estimation of relative risks, the complication rates observed were plotted against BMI (Fig. 1). This demonstrates clearly that no increase in overall morbidity risk for patients with BMI 20–30 exists. For patients with BMI indices less than 20 and greater than 30, a continual increase of the complication rate is apparent. A U-shaped curve representing the frequency of complications and postoperative adverse events at the extremes of the BMI range is evident.

4. Discussion

The increasing prevalence of obesity and its associated medical hazards are a considerable public health concern in most developed countries. Specifically, body mass indices greater than 30 are thought to be associated with excess surgical risks. Both age-adjusted prevalences of obese as well as extremely obese patients are likely to increase according to current US Nation Health And Nutrition Examination Survey [1] and European epidemiological data project EURALM.

A national health consensus conference on obesity surgery described an increase in demand for bariatric surgery, with potential candidates having a BMI ≥ 40 (representing approximately 100 lb excess body weight for a male and 80-lb excess for female patients). The Society for Bariatric Surgery noted an exponential increase of such operations performed over the last five years [6], with >100,000 of these major gastrointestinal procedures were performed in 2004 in the US alone. The operative risks of gastric resections or bypass procedures are both procedure- and patient-related. The risk stratification for other major surgical procedures have not been well defined.

In the era of risk stratification and informed consent, commonly applied estimation of open heart surgical risks may not adequately aim to assess obesity as a risk factor in various scoring systems [7,8]. Additionally, the highly predictive EuroSCORE does not include BMI stratification for cardiac surgical risk [9].

There are surprisingly few studies assessing complications in obese patients undergoing open heart surgery. Most authors provide retrospective studies with limited insight into selective adverse events, associated with coronary artery bypass grafting. Outcomes have not been shown to be adversely affected in patients below BMI of 40 in these studies. This study primarily assessed mortality and morbidity associated with BMI ≥ 40 and provides confirmation of low mortality in this patient group. Similarly, our evidence shows that obese patients can have an acceptable perioperative and 30-day mortality rate. In fact, our outcome data for the patients defined as extremely obese is similar to the non-obese patient group. A tertiary medical center with surgical experience in this patient group provides expertise that compensates for certain potential complications (Table 2).

Kuduvalli et al. reported an increased frequency of prolonged ventilation in patients with a BMI > 35 [10]. We confirmed that prolonged ventilation, based upon the definition of postoperative intubation greater than 24 h, is likely in obese and extremely obese patients undergoing

Table 2
Complications associated with BMI classifications

Complication	Non-obese (NonOb), BMI 20—30 (n = 1056)	Obese, BMI 30—40 (n = 592)	Extreme obese, BMI ≥ 40 (n = 79)	p value (overall)	p value (obese vs NonOb)	p value (extreme obese vs NonOb)
LOS (days ± SD)	9.574 ± 12.3	10.00 ± 12.7	11.43 ± 11.1	<0.001	0.036	<0.001
Intensive care unit time (hours ± SD)	58.3 ± 161.6	61.2 ± 516.0	84.4 ± 71.0	0.069	0.081	0.082
Complications, n (%)	487 (46.1)	277 (46.8)	45 (58.4)	0.112	0.797	0.044
Infection sternum deep	11 (1.0)	9 (1.5)	0 (0.0)	0.427	0.483	1
Infection septicemia	32 (3.0)	22 (3.7)	4 (5.2)	0.507	0.473	0.302
Neuro stroke permanent	30 (2.9)	16 (2.7)	4 (5.2)	0.469	1	0.285
Neuro stroke transient	27 (2.6)	10 (1.7)	3 (3.9)	0.342	0.300	0.453
Pulmonary prolonged ventilation	247 (23.5)	167 (28.3)	30 (39)	0.003	0.033	0.004
Pulmonary embolism	1 (0.1)	1 (0.2)	0 (0.0)	0.872	1	1
Pulmonary pneumonia	75 (7.1)	36 (6.1)	6 (7.8)	0.684	0.474	0.818
Renal failure	53 (5.0)	36 (6.1)	11 (14.3)	0.003	0.366	0.003
Renal dialysis required	24 (3.2)	19 (4.4)	4 (7.3)	0.211	0.322	0.113
Heart block	26 (2.5)	17 (2.9)	2 (2.6)	0.886	0.631	1
Cardiac arrest	39 (3.7)	19 (3.2)	4 (5.2)	0.656	0.677	0.530
Anticoagulation-related	33 (3.1)	15 (2.5)	0 (0.0)	0.245	0.544	0.162
Tamponade	6 (0.6)	2 (0.3)	0 (0.0)	0.664	0.719	1
GI complication	53 (5.0)	27 (4.6)	2 (2.6)	0.601	0.721	0.579
Atrial fibrillation	235 (22.3)	121 (20.6)	17 (22.4)	0.713	0.454	1
Reoperation, n (%)						
Bleed/tamponade	49 (4.7)	12 (2.0)	3 (3.9)	0.026	0.063	1
Valve dysfunction	1 (0.1)	1 (0.1)	0 (0.0)	0.873	1	1
Graft occlusion	0 (0.0)	0 (0.0)	1 (1.3)	0.046*	1	0.070
Other cardiac	20 (1.9)	9 (1.5)	0 (0.0)	0.425	0.698	0.391
Other	52 (4.9)	28 (4.7)	6 (7.8)	0.506	0.905	0.279
Mortality, n (%)						
Perioperative	16 (1.5)	7 (1.2)	0 (0.0)	0.492	0.666	0.619
Operative death	60 (8.4)	25 (6.7)	5 (10.6)	0.497	0.404	0.587
DC status	54 (5.1)	23 (3.9)	4 (5.1)	0.530	0.276	1
30-day status	49 (4.9)	21 (3.7)	4 (5.4)	0.501	0.309	0.780

* Result of Fisher's exact test in single patient.

major cardiac surgery. The use of bronchodilators following cardiac surgery was found to be increased in one prospective study [10]. The incidence of postoperative pneumonia did not differ across our BMI categories. Others observed frequent
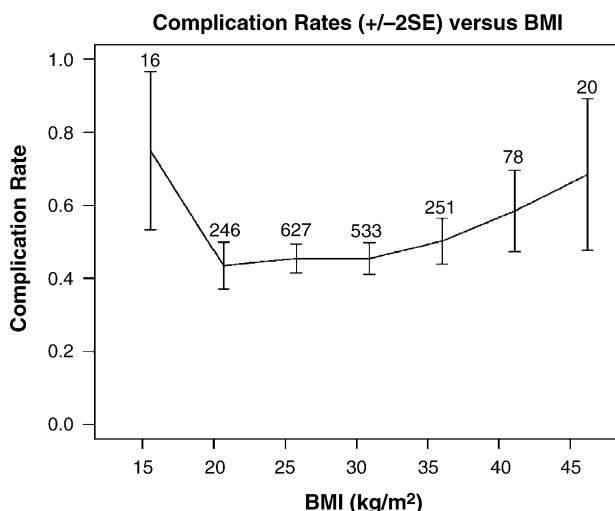

Fig. 1. Complication rates in open heart surgery plotted against BMI intervals. Patients were bundled to the closest BMI in successive intervals of approximate length five (13, 18.1), (18.1, 23.2), … (43.7, 48.8). Error bars represent two standard errors for each BMI-specific complication rate. Numbers above bars are the number of observations in the BMI interval; nine patients whose BMI exceeded 48.8 were excluded (complication rate 0.22 for these nine patients). The bundled groups are different than the BMI categories analyzed in our study.

respiratory impairment during the postoperative phase, but this has neither been well defined nor established in other reviews [11]. Obese patients are more likely to have a low respiratory reserve with a ventilation/perfusion mismatch and decreased functional residual capacity. This, however, has not led to adverse outcomes in intensive care medicine in the obese patient.

Our finding of increased acute renal failure, defined by creatinine rise two times from baseline and greater than 2.0 mM/ml, has not been previously reported in association with cardiac surgery in obese patients. However, this was not associated with a statistically significant increase in patients requiring renal dialysis for either obese or extremely obese patients. A previous prospective study did not show an association between acute renal failure and body mass index [10].

The previous reported finding that obese patients suffer a higher incidence of postoperative superficial or deep wound infections (INF) could not be verified in this retrospective analysis. The low risk observed in both the obese and extremely obese patient groups of sternal wound infections, probably reflect the use of the STS definition applied and the expertise developed at this tertiary center with high prevalence of morbid obesity. Gaynes et al. [12] reported a similar experience. In other studies, the expected incidence of postoperative mediastinitis has been linked to obesity but maybe mostly associated with diabetes mellitus and perioperative hyperglycemia with the presence of other comorbid conditions prevalent in this patient group [13—15].

Table 3
Association between obesity and complication

Outcome variables	Obese			Extremely obese		
	OR[*]	95% CI[†]	p value[‡]	OR[*]	95% CI[†]	p value[‡]
Overall complications	1.027	0.83–1.26	0.797	1.64	1.00–2.72	0.044
Length of stay	–	–	0.036	–	–	<0.001[a]
Reoperation bleeding	0.42	0.20–0.818	0.006	0.84	0.16–2.71	1
Prolonged ventilation	1.29	1.02–1.63	0.033	2.08	1.24–3.44	0.004
Renal failure	1.22	0.77–1.93	0.366	3.13	1.41–6.44	0.003

[a] P value calculated using Wilcoxon rank sum test; no odds ratio or 95% CI calculated.
[*] Odds ratio: the non-obese group is the referent category.
[†] CI is the 95% confidence interval.
[‡] p value calculated using Fisher's exact test.

Birkmeyer et al. [16] describe the rate of wound infections as up to three times higher in obese patients after adjustment of other predictors of this outcome. Moulton et al. [17] studied patients with a BMI > 30 and found increased superficial sternotomy wound infections and conduit harvest site infections. Similarly, a large retrospective study conducted by Engelmann et al. concluded that wound infections are more frequent in obese patients and observed a high incidence of deep sternal wound infections. Sternal wound infections were a major finding in five of the eight series reviewed. Loop et al. [13] established an odds ratio of 2.9 associated with obesity for sternal wound complications in a multivariate analysis of 6504 patients. Our population group did not show increased incision-related superficial or deep sternotomy wound infections (Table 2).

Findings regarding bleeding complications observed in this setting are controversial. A prospective cohort described by Birkmeyer et al. [16] showed decreased postoperative bleeding in obese patients (BMI > 31). This was not confirmed by a multivariate analysis of extremely obese patients with BMI > 36 [16]. Similarly, our obese patient group had a reduced risk of postoperative bleeding (Table 3). This may appear counterintuitive on first assessment but little information regarding bleeding propensity and hemostatic properties after major surgery in obese patients is available.

Only two studies with small patient cohorts studied product transfusion rates in obese patients after cardiac surgery. Uva et al. [18] found an increased transfusion rate while Ranucci et al. [11] found a decreased transfusion rate. The indications for transfusions and parameters used for blood products were poorly defined and no conclusive evidence is available to date [11,18]. The obese and extremely obese patients in our cohort did not show increased hemorrhage tendencies and required no more frequent blood product transfusions than non-obese cardiac surgical patients. In fact, a marked decrease for the need in reoperation for bleeding was observed in both obese patient groups in our retrospective analysis. Blood product use, defined as transfusion intraoperatively or postoperatively according to STS guidelines, was similar across all three groups and does not explain the decreased reoperation rate for obese patients.

A higher frequency of postoperative hypertension requiring pharmacological intervention was not observed in our obese patient group. This association was previously found in a single prospective study published in 1985 by Koshal et al. [10] but not confirmed by other authors. The high preoperative prevalence of hypertension as a co-morbid factor in this group does not pose a clinically prominent problem postoperatively. Similarly, diabetes mellitus present preoperatively in 54.5% of the extremely obese patients and 37.9% of the obese patients has not been shown to result in clinically relevant postoperative morbidity. Little information is available regarding the metabolic syndrome and glucose metabolism derangements in the obese cardiac patient in the postoperative phase. Contrary to bariatric surgery, where significant weight loss, remission of diabetes mellitus and improvement of lipid serum levels are observed, cardiac surgery in the extremely obese patient does not provide therapeutic interventions for these pre-existing comorbidities [19]. Continued long-term medical management is essential in improving life span.

In a relatively small retrospective study, Brandt et al. [20] have reported no statistically significant complication increases in obese patients. They report a discrepancy between total procedure time of CABG and discuss technical considerations in their obese patient group [20]. Procedural difficulty or operative hazards encountered in obese patients cannot be analyzed in this context. As with reoperations, for example, a certain level of expertise is required to avoid operative pitfalls as well as postoperative complications. It is apparent that with relatively minor adjustments intraoperative problems can be avoided.

Methodological differences alone may not conclusively explain the range of findings of the studies compared in Table 4. Most evidence provided has been extrapolated from relatively small prospective and retrospective studies. Two prospective multi-center studies were conducted adjusting for confounding factors including preoperative comorbidities [10,16].

Although a consensus definition for obesity and extreme obesity exists according to World Health Organization (WHO) and NHANES, authors have used variable BMI cutoffs to define their patient groups (Table 4). Other authors have defined obesity by percentage change from ideal body weight calculations [5]. The comparability of the studies available is therefore limited and does not allow for meta-analysis.

The majority of previous studies available have been conducted with the primary focus on coronary bypass surgery outcomes. Our patient population consisted of both valve and coronary surgical patients combined similar to the studies by Engelman et al. and Moulton et al. [17]. Our decision to exclude transplant and VAD surgeries is based upon previous studies demonstrating an increased mortality in obese

Table 4
Composite of reported statistically significant complications related to obesity in cardiac surgery [10,11,16,17,18,25]

Citation	Population size defined as obese (n)	Prospective versus retrospective	BMI cutoff defined as obese	Complication with statistically increased incidence compared to non-obese population
Koshal et al. [10]	99	Prospective	27	Brochodilator use ($p < 0.010$); wound infection ($p < 0.010$); postoperative hypertension ($p = 0.025$)
Ranucci et al. [11]	Female 37 Male 79	Prospective	28.6 30	Decreased need for blood products ($p = 0.009$); minor lung dysfunction ($p = 0.001$); leg wound infection ($p = 0.045$); sternal wound infection ($p < 0.05$)
Moulton et al. [17]	567	Retrospective	30	Superficial sternal wound infection ($p < 0.001$); leg infection ($p = 0.005$); atrial dysrhythmias ($p = 0.04$)
Engelman et al.[b]	1200	Prospective	30	New atrial fibrillation ($p = 0.02$)[a]: re-exploration for bleeding ($p = 0.005$)[a]; deep sternal wound infection ($p < 0.0001$)[a]; leg infection ($p < 0.0001$)[a]
Brandt et al. [20]	100	Retrospective	30	No significant complications noted
Kuduvalli et al. [25]	1041	Retrospective	30	Atrial arrhythmia ($p = 0.037$)[a]; sternal wound infection ($p = 0.002$)
Wigfield et al.	592	Retrospective	30	Length of stay ($p = 0.036$); reoperation bleeding ($p = 0.006$); prolonged ventilation ($p = 0.033$)
Birkmeyer et al. [16]	2220	Prospective	31	Decreased postoperative bleeding ($p = 0.002$); sternal wound infection ($p < 0.001$)
Kuduvalli et al. [25]	243	Retrospective	35	Atrial arrhythmia ($p = 0.008$)[a]; harvest site infection ($p < 0.001$); sternal wound infection ($p = 0.038$)[a]; mechanical ventilation > 48 h ($p = 0.004$); postoperative stay > 14 days ($p = 0.009$)[a]
Uva et al. [18]	50	Retrospective	35	Increased blood product use ($p = 0.003$)
Birkmeyer et al. [16]	556	Prospective	36	Decreased postoperative bleeding ($p = 0.006$); sternal wound infection ($p = 0.005$)
Wigfield et al.	79	Retrospective	40	Length of stay ($p < 0.001$); renal failure ($p = 0.003$); prolonged ventilation (>24 h) ($p = 0.004$)

[a] Adjusted.
[b] Engelman DT, Adams DH, Byrne JG, Aranki SF, Collins JJ, Couper GS, Allred EN, Cohn LH, Rizzo RJ. Impact of body mass index and albumin on morbidity and mortality after cardiac surgery. J Thorac Cardiovasc Surgery 1999;118:866—873.

transplant recipients. Although patients with cardiac surgery have similar perioperative complications, we assessed a more heterogeneous population of patients and therefore possibly introduced confounding variables. Our reference population is representative for a large tertiary surgical care center in the United States. The referral patterns reflect the demographics of this region and include the largest patient cohort described of extremely obese patients.

Risk stratification is the ultimate motivation for establishing complication rates in obese patients undergoing cardiac surgery. Preoperative evaluation of obese patient undergoing cardiac surgery provides an opportunity for an interdisciplinary approach to allow accurate risk stratification and informed patient choices. The approach for consenting patients, and the medico legal issues for consenting patients, has become a focus of daily clinical practice. Our data provides evidence that cardiac surgery is safe even for the extremely obese patient population.

Since obesity is a chronic condition, a potential risk reduction based on weight loss alone has to take into account the recidivism of weight loss programs. Behavior modifications, exercise, and diet are considered the mainstay of treatment for obesity. Few patients are successful in reducing their weight preoperatively, although some evidence suggests that patients generally have better recovery and increased mobility with major surgical procedures after

preoperative weight reduction [21,22]. Genetic factors may be responsible for up to 70% of the variation of patients weights [23]. It is critical to appreciate that patient's weights will fluctuate within 10% of a physiological set value and the regulation of BMI involves maintenance of energy balance as well as nutrient composition and physiological feedback mechanisms. Chronic imbalance between energy intake and energy expenditure seen in a majority of severely obese patients results in adipose tissue mass increases.

Leptin, a circulating protein of lipid homeostasis, may provide novel approaches to regulate adipose tissue proliferation and could theoretically reduce body mass indices in short term prior to cardiac surgery [24]. However, any effect on perioperative outcomes at present is speculative and this requires clinical investigation. Given the polygenic nature of severe obesity, the current constraints of weight loss programs, and the acute nature of cardiac diseases amenable to surgical intervention, deferring such procedures in obese patients may not be justifiable.

The limitations to this study are mostly linked to the retrospective nature of the analysis and to the lack of the ability to adjust for confounding variables. BMI was used to define obesity in this study population. The concept of normal weight and obesity are relative to the environmental and cultural factors, with every population presenting as a continuum of height and weight. WHO criteria for morbid

obesity in the Asian population, for example, differ compared to the applied NHANES population criteria. The clinical guidelines employed in this study are applied to the general population and are not specific to the cardiac surgical patients. This allows for a selection bias.

The clinical guidelines established by NHANES were employed in this study. They refer to the general population and are not specific to the cardiac surgical patients. This introduces a potential bias. The relatively small denominator for patients at the extreme end of the BMI spectrum of this study limits the statistical power and did not yield sufficient observations for a multivariate analysis of relatively infrequent complications. The occurrence of deep vein thrombosis, for example, would require a prospective assessment, as this is not currently part of the STS complication data set. A prospective evaluation of obesity as a risk factor for specific complications in cardiac surgery would, therefore, require pooled data from multiple centers in order to provide satisfactory power calculations to detect increased risk ratios with certainty.

In summary, extreme obesity according to our study and other data available is not associated with an increased mortality after cardiac surgery. Extremely obese patients have a statistically significant increase in frequency of specific complications, including prolonged ventilation and acute renal failure not requiring hemodialysis (HD). This may result in prolonged length of stay and may have economic health care consequences. Although it has been established that obese patients are not at an excessive adverse risk while undergoing CABG [10,11,16,20,25] or cardiac surgery utilizing cardiopulmonary bypass [17], further clinical investigation is required focusing on specific cardiac surgical procedures. To exclude patients from cardiac surgery due to high body mass index or quote excessive operative risks may not accurately reflect the evidence currently available.

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