Published in final edited form as:

J Gastrointest Surg. 2010 August ; 14(8): 1285–1291. doi:10.1007/s11605-010-1232-9.

Body Mass Index and Adverse Perioperative Outcomes Following Hepatic Resection

Amit K. Mathur,

Division of Transplantation, Department of Surgery, University of Michigan, Ann Arbor, MI, USA;
University of Michigan Health System, 2207 Taubman Center Box 5342, 1500 E Medical Center
Drive, Ann Arbor, MI 48109-5342, USA

Amir A. Ghaferi,

Division of Transplantation, Department of Surgery, University of Michigan, Ann Arbor, MI, USA

Nicholas H. Osborne,

Division of Transplantation, Department of Surgery, University of Michigan, Ann Arbor, MI, USA

Timothy M. Pawlik,

Department of Surgery, Johns Hopkins University, Baltimore, MD, USA

Darrell A. Campbell,

Division of Transplantation, Department of Surgery, University of Michigan, Ann Arbor, MI, USA

Michael J. Englesbe, and

Division of Transplantation, Department of Surgery, University of Michigan, Ann Arbor, MI, USA

Theodore H. Welling

Division of Transplantation, Department of Surgery, University of Michigan, Ann Arbor, MI, USA

Amit K. Mathur: amitmath@med.umich.edu

Abstract

Background—The effect of obesity on perioperative outcomes following hepatic resection is not clearly defined. We sought to understand the implications of obesity on post-hepatectomy outcomes in a nationally represented cohort of patients.

Methods—Using a retrospective cohort design, we studied the effect of obesity on complications and 30-day mortality using multivariable logistic regression using comprehensive clinical data from the American College of Surgeons National Surgical Quality Improvement Program (2005-2008).

Results—During our study period, 3,960 patients underwent hepatic resection; 32.4% had a normal body mass index (BMI; 18.5–24.9 kg/m²), 2.5% were underweight (<18.5 kg/m²), 33.4% were overweight (25.0–29.9 kg/m²), and 31.7% were obese (>30.0 kg/m²). 23.3% had at least one post-operative complication and the overall mortality rate was 2.5%. Compared to normal patients, obese patients had significantly higher unadjusted odds of having a complication (26.5% vs. 21.3%, OR 1.34, 95% CI 1.12–1.61) and dying (3.0% vs. 1.7%, OR 1.79, 95% CI 1.05–3.05). The obese were also more likely to have multiple complications compared to normal BMI patients (6.1% vs. 3.7%, OR 1.70, 95% CI 1.17–2.46). After risk adjustment, obesity was associated with attenuated but significantly higher odds of having any perioperative complication (OR 1.24, 95% CI 1.01–1.55), but was not a significant predictor of mortality.

Conclusions—After adjusting for other clinical factors, the degree of obesity is independently associated with an increasing complication rate but not mortality. Risk adjustment may not capture the total clinical risk of patients at the extremes of BMI.

Keywords

Body mass index; Liver resection; Hepatectomy; Complications; Outcomes; NSQIP

Introduction

An important concern in the changing patient landscape of hepatic surgery is the increased recognition of an obesity epidemic in the United States.¹ Of the US population, 65-70% is considered to be overweight or obese,¹ and this proportion is growing. This epidemic has raised significant concerns regarding health outcomes in this population due to the strong association of obesity with cardiovascular disease, dyslipidemia, diabetes mellitus, and other co-morbidities.²⁻⁶ The role of obesity in surgical decision-making has also received considerable attention, with efforts directed at understanding the risk of post-operative morbidity and mortality following major surgery.^{2,3,7} These efforts were initiated to help clinicians stratify risk and to counsel patients considering surgery, which can be difficult given differences between patients, procedural complexity, and the potential direct effects of obesity on the end organ.

The growing utilization of hepatobiliary surgical procedures in a more obese patient population demands that surgeons recognize the complex relationship between obesity and surgical outcomes.⁸⁻¹¹ Several single center studies have demonstrated that obesity has specific implications on the health of the liver, but our understanding of how obesity affects multi-system complications is limited by descriptions with modest sample size.¹²⁻¹⁴ In order to help hepatobiliary surgeons make better decisions in the pre-operative setting with regards to patient selection and counseling as well as to properly allocate hospital resources, it is critical that the relationship between obesity and perioperative outcomes be studied using high quality multi-center data.

The American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) offers a unique opportunity to study the relationship between obesity and surgical outcomes following hepatic surgery. This database prospectively collects data on over 30,000 surgical patients in over 200 hospitals in the USA each year. It has detailed data regarding patient perioperative risk and postoperative outcomes. Using the ACS-NSQIP, we have analyzed the outcomes of nearly 4,000 patients who underwent hepatectomy over a four year period to determine how body mass index (BMI) affects postoperative risk following hepatectomy.

Methods

We obtained pooled multi-institutional data from the American College of Surgeons National Surgical Quality Improvement Program from 2005-2008. This program is the only validated and risk-adjusted outcomes based program aimed to improve the delivery of general surgical care in the US¹⁵ These data are collected from several participating centers by trained surgical clinical reviewers at each site, and submitted to the central registry. The data collection includes 136 clinical and demographic variables on pre-operative and intra-operative care, as well as post-operative morbidity and mortality (within 30 days post-operatively). The data collection techniques are continuously monitored for internal and external validity, and inter-rater reliability.¹⁵ This data is available through the ACS-NSQIP website to participating institutions.

The primary exposure variable was BMI, divided categorically in accordance to World Health Organization definitions of obesity, into underweight (BMI<18.5), normal (BMI 18.5-24.9), overweight (BMI 25.0-29.9), and obese (BMI>30).⁶ The primary outcome measures were the rates of complications and post-operative 30-day mortality. Complications included deep and organ-space surgical site infections, pneumonia, acute renal failure, myocardial infarction, venous thromboembolism, stroke, post-operative bleeding requiring blood transfusion, septic shock, unplanned intubation, mechanical ventilation (>48 h), and fascial dehiscence.

The principal aim of this analysis was to determine if patient obesity was associated with higher complication and 30-day mortality rates. We compared patient demographics and co-morbidities by obesity class, and calculated unadjusted complication and mortality rates, using Student's *t* test or chi-square where appropriate. In order to determine the specific risk of obesity, we used logistic regression techniques to determine risk-adjusted complication and mortality rates, accounting for several pre-operative clinical risk factors. These factors included age, gender, race, diagnosis, type of resection, functional status, American Society of Anesthesiology (ASA) preoperative risk classification, and co-morbidity burden.

This project was approved by the University of Michigan Institutional Review Board. All statistical analyses were performed using Stata version 10.0 (StataCorp, College Station, TX, USA). Statistical significance was considered at $p<0.05$.

Results

The clinical and demographic characteristics of 3,960 patients in the study cohort are listed by BMI classification in Table 1. 2.5% were underweight ($n=98$), 32.4% had a normal body mass index ($n=1,284$), 33.4% were overweight ($n=1,323$), and 31.7% were obese ($n=1,255$). Overweight patients were the oldest of the cohort, but the average age of each group ranged from 55 to 60 years. Of the total cohort, 33.5% was male ($n=1,329$). The underweight group had the largest proportion of female individuals. The underweight classification also had a significantly greater proportion of non-white patients at 23.2%. The types of operations differed significantly by BMI classification. Obese patients accounted for 2.7-6.2% more segmental resections than other patients. More than 14% of underweight patients underwent trisegmentectomy compared to approximately 8-10% of the patients in the other groups. Only 1.5% ($n=56$) of patients were coded as having liver tumor ablation (radiofrequency, chemical, or cryo-ablation) prior to liver resection. Obese patients had a slightly higher rate of ablation compared to the other groups, but this was not significant. With regards to co-morbidities, statistically significant differences among the four BMI classifications were observed with regards to hypertension, diabetes, active smoking, dialysis dependence, recent weight loss, and ASA class. Obese patients were more likely to be hypertensive and diabetic, but significantly less likely to be active smokers in the last year compared to normal and underweight patients. The underweight patients had a greater propensity toward dialysis dependence, and moribund ASA class. Notably, there were no significant differences between the groups with regards to the various metrics that could be attributed to preexisting liver disease, specifically ascites and varices.

The overall rate of complications was 23.3%, and the overall mortality rate was 2.5%. Cumulatively, obese patients had the highest unadjusted complication rate ($p=0.0051$; Fig. 1). Obese patients had 34% higher odds of having a complication in an unadjusted model (OR 1.34, 95% CI 1.12-1.61), while underweight and overweight patients, respectively, did not have significantly different odds of complications compared to normal BMI patients. The obese group had the highest proportion of patients who had three or more complications (obese 6.1% vs. overweight 4.1% vs. normal 3.7% vs. underweight 5.1%). Obese patients

also had greater unadjusted odds of having multiple complications (≥ 3 complications: OR 1.69, 95% CI 1.17-2.46). While the mortality rate across the BMI distribution was highest in the underweight group, underweight patients did not have significantly higher odds of mortality in the unadjusted regression model (OR 1.34, 95% CI 0.84-2.14), likely related to the small sample size of this group. Only obese patients had significantly higher odds of death following hepatectomy in this model (OR 1.79, 95% CI 1.05-3.05). These models suggest that the baseline morbidity and mortality risk for obese patients was substantial.

With regards to specific complications, on unadjusted analysis, obese patients had significantly higher rates of several complications (Table 2). Superficial surgical site infection and progressive renal insufficiency were greater than two-fold more common among the obese compared to the normal BMI patients, respectively. Underweight patients had a ten-fold higher risk of stroke compared to normal BMI patients ($p=0.014$). A greater proportion of obese patients required mechanical ventilation for greater than 48 hours after operation, which approached statistical significance ($p=0.051$). Underweight patients had a greater proportion of pneumonia, unplanned intubations, acute renal failure, organ space infections, and septic shock than other patients, but these findings did not reach statistical significance.

After adjusting for the clinical co-morbidities in Table 1, the effect of obesity on complication rates was attenuated (Fig. 2). Obese patients had 24% higher risk-adjusted odds of having a complication following hepatectomy compared to normal BMI patients (OR 1.24, 95% CI 1.01-1.55). Underweight patients also trended toward higher complication rates compared to normal BMI patients, but this was not significant (OR 1.17, 95% CI 0.67-2.06). Obese and normal patients had similar odds of having multiple complications as well (≥ 3 complications, obese vs. normal, OR 1.49, 95% CI 0.97-2.28). With regards to risk-adjusted mortality, as BMI increased, the risk of dying after hepatectomy appeared to increase in a stepwise fashion, but this did not reach statistical significance. Notably, obese patients trended toward an 80% higher risk of postoperative death compared to normal BMI patients (OR 1.83, 95% CI 0.98-3.46, $p=0.059$), but this risk was abrogated by covariate-adjustment.

We subsequently analyzed the effect of obesity on complications and mortality using the subset of hepatic surgery patients who underwent major resections ($n=1,626$). In both the unadjusted and risk-adjusted models, obesity was neither associated with significantly increased complication rates nor mortality rates (Table 3).

Discussion

The growing obesity epidemic in the USA and the expansion of clinical indications for liver surgery over the last decade has greatly changed the population of patients undergoing hepatic resection. With growing utilization of these procedures, greater potential benefit is available to patients, and clinical risks may become redefined. We have attempted to define the risks of perioperative morbidity and mortality following hepatectomy based on BMI using a recent cohort of patients. We found that patients with BMI greater than 30 are at significantly higher risk of post-operative complications and a higher risk of mortality in the subsequent 30 days following the hepatectomy. After risk-adjusting for clinical co-morbidities, however, the potential for complications in the obese declined, and the mortality risk was similar to that of normal patients. These findings have significant clinical implications.

Several authors have identified obesity as a significant risk factor in complex general, oncologic, and vascular surgery procedures.^{2-4,12,14,16-19} These studies frame a growing

problem in surgery—the operative and perioperative challenges of managing an obese patient with complex surgical needs. These challenges clearly apply to the management of the obese hepatic surgery patient, and we, among others, have identified obesity as a predictor of several perioperative complications including hepatic-specific complications, biliary leaks, urosepsis, pneumonia, acute renal failure, and deep space organ infections.^{5,17,20–22} The relationship between obesity and complications in these studies is largely derived from single center retrospective experiences, and has not been validated using multi-center data. The intent of our study was to stratify the independent risk of BMI in a patient population undergoing hepatic resection. Our study cohort is the largest to date with nearly 4,000 patients and represents the pooled outcomes of several centers providing hepatobiliary surgical care in the modern era. Our current findings have the most face validity as they are derived from high quality prospectively collected data specifically obtained to study clinical outcomes.

The persistence of the associations between obesity and perioperative morbidity and, arguably, mortality in our models after risk-adjusting for clinical co-morbidities is an important finding. The risk-adjustment for co-morbidities that may commonly occur in the obese may actually be adjusting away the clinical differences that we care about clinically, which signifies the importance of the magnitude of the effect observed in unadjusted analyses. The absence of any relationship between obesity and adverse outcomes in patients who had major hepatic resections suggests that careful pre-operative selection of even obese patients may not jeopardize reasonable clinical outcomes.

However, other mediators may play a role in this pathway, which may be biological or non-biological. One potential mediator is the degree of hepatic steatosis. Hepatic steatosis is associated both with high BMI and with a propensity for postoperative complications.^{14,23} Unfortunately, measurement of hepatic steatosis is reliant on liver biopsy and is wrought with problems with inter-rater reliability,²⁴ making it difficult to use for surgical decision-making in the pre-operative setting. Further, the collection of data on the extent of hepatic steatosis by clinical registries and administrative databases is sparse at best, making it difficult to assess its role on population-based outcomes, including this study. In order to elucidate any potential relationship between steatosis, BMI, and surgical outcomes, more robust analyses including both of these variables and outcomes must be performed to better understand this interaction, perhaps using multi-center data specifically collected for hepatobiliary surgical outcome studies.

Another important finding in this analysis relates to the risk at the extremes of body mass index. Prior to risk adjustment, we observed disproportionately high rates of overall and specific complications in the underweight group, who also displayed twofold higher mortality compared to normal patients. The risk adjustment and small sample size likely adjusted away clinically significant risk in this population in the regression models. Previous authors have also described this relationship in patients undergoing major operations for intra-abdominal cancer.⁴ These findings are likely related to the frail state of underweight patients, and hepatobiliary surgeons should consider intensive pre-operative evaluation and nutritional support prior to proceeding with hepatic resections. Further, patients at the other extreme of BMI may also be at increased risk. We performed sensitivity analyses to assess the effect of morbid obesity (BMI greater than 35) on these outcomes, but did not observe a relationship. Morbidly obese patients accounted for less than 5% of the entire cohort, and the lack of an observed relationship may be either related to the selection of “healthy” morbidly obese or related to a lack of statistical power.

The findings of our study must be considered in the context of its limitations. One criticism of the ACS-NSQIP data source is the lack of data on procedure-specific complications,

including liver failure and encephalopathy. This greatly limited our ability to determine the impact of obesity on liver-specific complications, which is also of great interest. Further, the risk adjustment did not include pre-operative treatments, such as neo-adjuvant chemotherapy, tumor ablation, or cancer stage, which may affect potential outcomes.^{25–27} The addition of other pre-operative and post-operative procedures may induce a greater risk for hepatectomy patients, which means better data would improve risk adjustment. Another limitation is related to the non-significant relationship between obesity and mortality in the total cohort, which was attributed to the risk-adjustment schema. We were limited by the data source to examining 30-day mortality but longitudinal data or a 60-day cut point may have been more informative. Next, the association observed in this study may also be affected by variation in surgical and perioperative practice patterns. The ACS-NSQIP does not provide unique center identifiers in its public use data, and our findings could not be adjusted for the differences in perioperative management, patient selection, mortality after complications, and surgical volume that may differ across centers which may ultimately affect variation in postoperative outcomes for this patient population.^{28,29}

The significance of the relationship between obesity and perioperative morbidity following hepatic resection must also be considered in the context of healthcare delivery. The association observed was a summative estimate, and the relationship may not hold true for individual patients who are unique. Obese patients can be difficult to manage perioperatively, and there may be considerable variability in the processes of care that may contribute to heterogeneity in outcomes. Further study is required in order to determine the role of center practices on outcomes of hepatobiliary surgery in the obese population, in order to assist in the development of quality improvement initiatives in centers that provide hepatobiliary surgical care.

Regardless of the effects of centers, ultimately, surgeons bear the responsibility of counseling their patients on the risks of hepatic surgery. Any consideration of the perioperative risks identified in this study must be weighed against reasonable long-term outcomes observed elsewhere in the obese population.¹⁷ Hepatobiliary surgeons should counsel patients in this context, and should focus on improvements in perioperative care that they may affect in order to improve the rate and management of surgical complications. With greater focus on surgical quality improvement in recent years, it is incumbent upon providers performing the most high-risk operations to evaluate practices to optimize clinical outcomes.

Acknowledgments

AKM and AAG are supported by T32 CA009672-18. NHO is supported by the Robert Wood Johnson Clinical Scholars Program.

References

1. Ogden CL, Yanovski SZ, Carroll MD, Flegal KM. The epidemiology of obesity. *Gastroenterology* 2007;132(6):2087–2102. [PubMed: 17498505]
2. Anaya DA, Dellinger EP. The obese surgical patient: a susceptible host for infection. *Surg Infect (Larchmt)* 2006;7(5):473–480. [PubMed: 17083313]
3. Doyle SL, Lysaght J, Reynolds JV. Obesity and post-operative complications in patients undergoing non-bariatric surgery. *Obes Rev.* 2009
4. Mullen JT, Davenport DL, Hutter MM, Hosokawa PW, Henderson WG, Khuri SF, et al. Impact of body mass index on perioperative outcomes in patients undergoing major intra-abdominal cancer surgery. *Ann Surg Oncol* 2008;15(8):2164–2172. [PubMed: 18548313]
5. Pitt HA. Hepato-pancreato-biliary fat: the good, the bad and the ugly. *HPB (Oxford)* 2007;9(2):92–97. [PubMed: 18333122]

6. Obesity: preventing and managing the global epidemic. Report of a WHO consultation. World Health Organ Tech Rep Ser 2000;894:i–xii. 1–253. [PubMed: 11234459]
7. Merkow RP, Bilimoria KY, McCarter MD, Bentrem DJ. Effect of body mass index on short-term outcomes after colectomy for cancer. *J Am Coll Surg* 2009;208(1):53–61. [PubMed: 19228503]
8. Dimick JB, Wainess RM, Cowan JA, Upchurch GR Jr, Knol JA, Colletti LM. National trends in the use and outcomes of hepatic resection. *J Am Coll Surg* 2004;199(1):31–38. [PubMed: 15217626]
9. Dimick JB, Cowan JA Jr, Knol JA, Upchurch GR Jr. Hepatic resection in the United States: indications, outcomes, and hospital procedural volumes from a nationally representative database. *Arch Surg* 2003;138(2):185–191. [PubMed: 12578418]
10. Lyratzopoulos G, Tyrrell C, Smith P, Yelloly J. Recent trends in liver resection surgery activity and population utilization rates in English regions. *HPB (Oxford)* 2007;9(4):277–280. [PubMed: 18345304]
11. Majeed AW, Price C. Resource and manpower calculations for the provision of hepatobiliary surgical services in the UK. *Ann R Coll Surg Engl* 2004;86(2):91–95. [PubMed: 15005925]
12. Vetelainen R, van Vliet A, Gouma DJ, van Gulik TM. Steatosis as a risk factor in liver surgery. *Ann Surg* 2007;245(1):20–30. [PubMed: 17197961]
13. Ryan CK, Johnson LA, Germin BI, Marcos A. One hundred consecutive hepatic biopsies in the workup of living donors for right lobe liver transplantation. *Liver Transplant* 2002;8(12):1114–1122.
14. Kooby DA, Fong Y, Suriawinata A, Gonen M, Allen PJ, Klimstra DS, et al. Impact of steatosis on perioperative outcome following hepatic resection. *J Gastrointest Surg* 2003;7(8):1034–1044. [PubMed: 14675713]
15. American College of Surgeons National Surgical Quality Improvement Program. ACS NSQIP Data Collection Overview. [20 Jan 2010]. Available from https://acsnsqip.org/main/program_data_collection.asp
16. Davenport DL, Xenos ES, Hosokawa P, Radford J, Henderson WG, Endean ED. The influence of body mass index obesity status on vascular surgery 30-day morbidity and mortality. *J Vasc Surg* 2009;49(1):140–147. [PubMed: 19028047]
17. Mathur AK, Ghaferi AA, Sell K, Sonnenday CJ, Englesbe MJ, Welling TH. Influence of obesity on complications and oncologic outcomes following hepatectomy for malignancy. *J Gastrointest Surg* 2010;14(5):849–857. [PubMed: 20140536]
18. Okabayashi T, Nishimori I, Yamashita K, Sugimoto T, Yatabe T, Maeda H, et al. Risk factors and predictors for surgical site infection after hepatic resection. *J Hosp Infect* 2009;73(1):47–53. [PubMed: 19640610]
19. Bennis M, Woodall C, Scoggins C, McMasters K, Martin R. The impact of obesity on outcomes following pancreatic resection for malignancy. *Ann Surg Oncol* 2009;16(9):2565–2569. [PubMed: 19557479]
20. Gedaly R, McHugh PP, Johnston TD, Jeon H, Ranjan D, Davenport DL. Obesity, diabetes, and smoking are important determinants of resource utilization in liver resection: a multicenter analysis of 1,029 patients. *Ann Surg* 2009;249(3):414–419. [PubMed: 19247028]
21. House MG, Fong Y, Arnaoutakis DJ, Sharma R, Winston CB, Protic M, et al. Preoperative predictors for complications after pancreaticoduodenectomy: impact of BMI and body fat distribution. *J Gastrointest Surg* 2008;12(2):270–278. [PubMed: 18060467]
22. Behrns KE, Tsiotos GG, DeSouza NF, Krishna MK, Ludwig J, Nagorney DM. Hepatic steatosis as a potential risk factor for major hepatic resection. *J Gastrointest Surg* 1998;2(3):292–298. [PubMed: 9841987]
23. Gomez D, Malik HZ, Bonney GK, Wong V, Toogood GJ, Lodge JP, et al. Steatosis predicts postoperative morbidity following hepatic resection for colorectal metastasis. *Br J Surg* 2007;94(11):1395–1402. [PubMed: 17607707]
24. El-Badry AM, Breitenstein S, Jochum W, Washington K, Paradis V, Rubbia-Brandt L, et al. Assessment of hepatic steatosis by expert pathologists: the end of a gold standard. *Ann Surg* 2009;250(5):691–697. [PubMed: 19806055]

25. Pawlik TM, Olino K, Gleisner AL, Torbenson M, Schulick R, Choti MA. Preoperative chemotherapy for colorectal liver metastases: impact on hepatic histology and postoperative outcome. *J Gastrointest Surg* 2007;11(7):860–868. [PubMed: 17492335]
26. Zorzi D, Laurent A, Pawlik TM, Lauwers GY, Vauthey JN, Abdalla EK. Chemotherapy-associated hepatotoxicity and surgery for colorectal liver metastases. *Br J Surg* 2007;94(3):274–286. [PubMed: 17315288]
27. Vauthey JN, Pawlik TM, Ribero D, Wu TT, Zorzi D, Hoff PM, et al. Chemotherapy regimen predicts steatohepatitis and an increase in 90-day mortality after surgery for hepatic colorectal metastases. *J Clin Oncol* 2006;24(13):2065–2072. [PubMed: 16648507]
28. Ghaferi AA, Birkmeyer JD, Dimick JB. Complications, failure to rescue, and mortality with major inpatient surgery in medicare patients. *Ann Surg* 2009;250(6):1029–1034. [PubMed: 19953723]
29. Ghaferi AA, Birkmeyer JD, Dimick JB. Variation in hospital mortality associated with inpatient surgery. *N Engl J Med* 2009;361(14):1368–1375. [PubMed: 19797283]

Fig. 1. Unadjusted complication and 30-day mortality rates following hepatectomy by obesity classification. By obesity classification, the frequency of having a complication and mortality follow a U-shaped distribution, respectively. Underweight and obese patients had significantly higher complication rates than normal BMI patients ($p=0.0051$). The 30-day postoperative mortality rate was higher among underweight, overweight, and obese patients compared to normal BMI patients, respectively.

Fig. 2.

Risk-adjusted odds of complications and perioperative mortality following hepatectomy by obesity classification. The risk-adjusted odds of complications and mortality are displayed in these Forest plots. Following risk-adjustment, obese patients had significantly higher, but attenuated, odds of having a complication compared to normal patients. Despite displaying higher unadjusted odds toward mortality following hepatectomy, obese patients had similar risk-adjusted mortality risk as normal BMI patients. Notably, the underweight patients did not have significantly different odds of having a complication or death than normal BMI patients after risk adjustment. This is most likely related to the small sample size in the underweight group.

Table 1
Preoperative Characteristics of 3,960 Patients who underwent Hepatectomy by Obesity Classification

	Underweight BMI <18.5 (n=98)	Normal BMI 18.5-25 (n=1,284)	Overweight BMI 25-29 (n=1,323)	Obese BMI ≥30 (n=1,255)	p value
Age (mean ± SD)	55.1±16.0	57.4±14.8	60.0±12.8	57.5±12.8	<0.001
Gender (% male)	21.40%	29.40%	40.20%	31.63%	<0.001
Race (% non-white)	23.20%	16.20%	13.50%	13.70%	<0.017
Type of resection					0.047
Segmental resection (cpt 47120; n=2337)	60.2%	57.4%	56.7%	62.9%	
Right hepatectomy (cpt47130; n=835)	19.4%	21.7%	22.0%	19.6%	
Left hepatectomy (cpt 47125; n=401)	6.1%	10.3%	10.9%	9.4%	
Trisegmentectomy (cpt 47122; n=390)	14.3%	10.6%	10.4%	8.1%	
Pre-operative liver tumor ablation (n=56)	2.6%	3.3%	3.0%	4.3%	0.673
Functional status					<0.001
Independent	90.80%	98.52%	98.95%	97.21%	
Partially dependent	9.20%	1.32%	0.75%	2.23%	
Totally dependent	0%	0.16%	0.30%	0.56%	
Hypertension	24.49%	31.67%	46.26%	61.12%	<0.001
Diabetes	4.08%	6.54%	10.11%	18.57%	<0.001
Active smoker in last year	30.60%	18.90%	13.10%	13.80%	<0.001
Chronic obstructive pulmonary disease	37.76%	37.00%	32.38%	34.34%	0.088
Congestive heart failure	0%	0.39%	0.23%	0.16%	0.644
History of myocardial infarction	31.60%	35.10%	30.87%	31.79%	0.118
Dialysis dependence	3.06%	0.62%	0.23%	0.48%	0.002
Weight loss >10% in last 6 months	43.88%	40.31%	33.81%	33.94%	<0.001
Ascites	2.04%	1.32%	1.13%	1.75%	0.543
Esophageal varices	0.00%	0.23%	0.45%	0.64%	0.413
ASA class ≥4	5.10%	2.65%	3.00%	3.35%	<0.001
MELD score (median; IQR)	7 (6-16)	7 (6-22)	7 (6-24)	7 (6-23)	0.06
Albumin <3.5	18.37%	12.06%	10.57%	12.27%	0.095
Platelet Ct >100	94.62%	97.77%	96.87%	96.87%	0.21
Total bilirubin >2.0	19.39%	12.76%	13.43%	13.15%	0.318

Table 2

Unadjusted Complication Rates Following Hepatectomy By Obesity Classification

	Underweight BMI <18.5 (n=98; %)	Normal BMI 18.5-25 (n=1,284; %)	Overweight BMI 25-29 (n=1,323; %)	Obese BMI ≥30 (n=1,255; %)	p value
Superficial surgical site infection	5.10	3.19	4.75	7.57	0.001
Stroke	1.02	0.08	0.60	0.08	0.014
Progressive renal insufficiency	1.02	0.62	0.53	1.59	0.020
Mechanical ventilation >48 h	5.10	3.66	3.92	5.74	0.051
Pneumonia	6.12	2.41	2.19	2.47	0.115
Unplanned intubation	6.12	3.27	3.70	3.67	0.522
Deep vein thrombosis	2.04	1.17	1.21	1.27	0.898
Urinary tract infection	6.12	4.36	3.32	4.86	0.182
Acute renal failure	2.04	1.01	1.58	1.51	0.541
Myocardial infarction	0.00	0.31	0.08	0.48	0.25
Pulmonary embolism	0.00	0.93	1.89	1.51	0.124
Postoperative bleed	0.00	0.93	0.98	0.88	0.801
Deep wound infection	1.02	0.62	0.98	1.27	0.414
Organ space infection	8.16	7.00	6.11	6.85	0.728
Septic shock	3.06	2.18	2.42	2.79	0.768
Fascial dehiscence	1.02	0.78	0.83	1.12	0.815

Table 3
Complication and Mortality Risk Following Major Hepatic Resection by Obesity Classification

	Unadjusted Model			Risk-adjusted model		
	OR	95% CI	p value	OR	95% CI	p value
30-Day mortality						
Underweight BMI <18.5 (n=39)	2.22	0.483-10.2	0.305	0.26	0.016-4.17	0.339
Normal BMI 18.5-25 (n=547)	1.00	Reference	Reference	1.00	Reference	Reference
Overweight BMI 25-29 (n=574)	1.56	0.77-3.15	0.214	1.28	0.53-3.11	0.584
Obese BMI>30 (n=466)	1.46	0.70-3.07	0.317	1.27	0.51-3.16	0.609
Complications						
Underweight BMI <18.5 (n=39)	1.49	0.76-2.95	0.246	1.25	0.547-2.87	0.594
Normal BMI 18.5-25 (n=547)	1.00	Reference	Reference	1.00	Reference	Reference
Overweight BMI 25-29 (n=574)	0.92	0.71-1.21	0.581	0.82	0.60-1.12	0.209
Obese BMI>30 (n=466)	1.16	0.88-1.52	0.290	1.16	0.85-1.59	0.351

Major hepatectomy included right and left hepatic lobectomy and trisegmentectomy (cpt codes=47122, 47125, 47130). Segmental resections were excluded (cpt code 47120)