Is There a Safe Lipoaspirate Volume? A Risk Assessment Model of Liposuction Volume as a Function of Body Mass Index

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Background: No concrete data exist to support a specific volume at which liposuction becomes unsafe; surgeons rely on their own estimates, professional organization advisories, or institutional or government-imposed restrictions. This study represents the first attempt to quantify the comprehensive risk associated with varying liposuction volumes and its interaction with body mass index.
Methods: Suction-assisted lipectomies were identified from the Tracking Operations and Outcomes for Plastic Surgeons database. Multivariate regression models incorporating the interaction between liposuction volume and body mass index were used to assess the influence of liposuction volume on complications and to develop a tool that returns a single adjusted odds ratio for any combination of body mass index and liposuction volume. Recursive partitioning was used to determine whether exceeding a threshold in liposuction volume per body mass index unit significantly increased complications.
Results: Sixty-nine of 4534 patients (1.5 percent) meeting inclusion criteria experienced a postoperative complication. Liposuction volume and body mass index were significant independent risk factors for complications. With progressively higher volumes, increasing body mass index reduced risk (OR, 0.99; 95 percent CI, 0.98 to 0.99; $p = 0.007$). Liposuction volumes in excess of 100 ml per unit of body mass index were an independent predictor of complications (OR, 4.58; 95 percent CI, 2.60 to 8.05; $p < 0.001$).
Conclusions: Liposuction by board-certified plastic surgeons is safe, with a low risk of life-threatening complications. Traditional liposuction volume thresholds do not accurately convey individualized risk. The authors' risk assessment model demonstrates that volumes in excess of 100 ml per unit of body mass index confer an increased risk of complications. (*Plast. Reconstr. Surg.* 136: 474, 2015.)
CLINICAL QUESTION/LEVEL OF EVIDENCE: Therapeutic, III.

Liposuction is one of the most commonly performed procedures in plastic surgery, with over 200,000 procedures performed annually.[1] Since its introduction, the procedure has evolved in both concept and application, becoming widely practiced by both plastic surgeons and other physicians. The advent of wetting solutions has allowed larger volumes of lipoaspirate to be removed while minimizing blood loss; however, large infusion volumes have caused fluid shifts and lidocaine toxicity to become significant safety concerns.[2–4] Substantial perioperative hemodynamic changes have been described in both animal and human studies, including increases in cardiac output, mean arterial pressure, central venous pressure, heart rate, and pulmonary pressure.[5–7] Despite these observations, the clinical

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Received for publication January 12, 2015; accepted February 26, 2015.

DOI: 10.1097/PRS.0000000000001498

Disclosure: *Dr. Kim receives research funding from and is a consultant for the Musculoskeletal Transplant Foundation. Mr. Hume is employed by and Dr. Murphy is the past president of the American Society of Plastic Surgeons. All other authors have no relevant financial relationships to disclose. This particular research received no external funding.*

implications remain unclear, as large volumes of infiltrated solution are generally well tolerated in healthy subjects, and several large series have confirmed the overall safety of liposuction.[7–12]

However, with liposuction being performed by untrained professionals, in nonaccredited office settings, and with continually increasing lipoaspirate volumes, reports of serious complications have surfaced, prompting scrutiny into procedural safety.[13–17] The reported incidence of death after liposuction varies dramatically between 2.6 and 20.6 per 100,000.[10,18–20] In an American Society for Aesthetic Plastic Surgery survey, thromboembolism, abdominal/viscus perforation, fat embolism, and cardiorespiratory failure were the most common discernible causes of death. The majority of deaths had no identifiable cause, leading to speculation that unrecognized volume overload and lidocaine toxicity may be more significant precipitants of mortality than previously thought.[20,21]

Today, significant controversy continues to surround the maximum permissible lipoaspirate volume. There are currently no quantitative data to support a specific volume at which point liposuction is considered unsafe.[9,22,23] The current American Society of Plastic Surgeons guidelines defines 5000 ml of aspirate as large-volume liposuction that likely portends increased procedural risk, despite concluding that "there is no scientific data available to support a specific volume maximum at which liposuction is no longer safe."[24,25] Recently, the utility of lipoaspirate volume as a proxy for procedural risk has been questioned, as varying volumes of wetting solution may be infused with different amounts of fat removed in the same total lipoaspirate volume, depending on the technique used, a fact not adequately accounted for by simply quantifying liposuction volume.[4,9,26] Furthermore, in a prospective study of patients undergoing liposuction, Swanson described the deceptive nature of estimating blood loss based on the negligible levels of hematocrit found in lipoaspirate, which typically accounts for only 2 percent of the blood loss experienced during liposuction.[27] Nonetheless, current guidelines recommend that large-volume liposuction (>5000 ml aspirate) be performed in an acute-care hospital setting for proper monitoring.[24,25]

Given limited empirical guidelines, plastic surgeons have relied on subjective estimates of the safe lipoaspirate volume based on a patient's medical condition, body mass index, concomitant procedures, and the potential physiologic consequences of liposuction.[24,25,28] The introduction and advent of individualized risk calculators such as the Breast Reconstruction Risk Assessment score underlines increased physician and patient demand for empiric and patient-centric data in an effort to capture more nuanced and quantitative measures of risk than typical population-based measures.[29–32] In this study, we endeavored to quantify the effect of liposuction volume on postoperative complication rates and evaluate whether the current 5000-ml large-volume definition is a valid threshold for procedural risk. Using the American Society of Plastic Surgeons Tracking Operations and Outcomes for Plastic Surgeons database, we developed the first risk stratification tool to determine the effect of lipoaspirate volumes and preoperative body mass index on complication rates and to propose a novel cutoff for safety in liposuction using both lipoaspirate volume and body mass index.

PATIENTS AND METHODS

Patient Selection

This study is based on the Tracking Operations and Outcomes for Plastic Surgeons program, which provides Health Insurance Portability and Accountability Act–compliant, deidentified databases to members and candidate members of the American Society of Plastic Surgeons. The program's registry contains more than 1 million plastic surgery procedures and has been previously described in detail and validated in several publications.[33,34] Patients were identified using Current Procedural Terminology codes for suction-assisted lipectomy of the head and neck (15876), trunk (15877), upper extremity (15878), and lower extremity (15879). The Procedure Description variable was queried to exclude patients who underwent procedures other than suction-assisted lipectomy. Duplicate cases were eliminated based on case identification number.

Preoperative Variables and Outcomes

Preoperative demographic variables collected by the registry include age, body mass index, sex, American Society of Anesthesiologists physical status class, active smoking, and diabetes. Operative details included patient admission status, type of anesthesia, liposuction volume, and operative time.

Postoperative complications were categorized as overall complications, surgical complications, medical complications, and any return to the hospital. Overall complications were defined by the presence of either a surgical complication, a medical complication, or an unplanned

return to the hospital. Surgical complications included seroma, hematoma, and superficial or deep incisional surgical-site infections. Medical complications consisted of venous thromboembolism including deep vein thrombosis and pulmonary embolism, cardiac complications, neurologic complications, respiratory complications, renal/genitourinary complications, and blood loss requiring transfusion. Unplanned return to the hospital included unplanned emergency room visits, readmissions, or return to the operating room.

Statistical Analysis

Patients were stratified into cohorts based either on criteria for large-volume liposuction (>5000 ml total aspirate) or the presence of at least one complication and compared using Pearson chi-square test or Fisher's exact test as appropriate for categorical variables and *t* tests for quantitative variables. Logistic regression was used to assess the impact of liposuction volume on complication rates while controlling for body mass index, age, sex, American Society of Anesthesiologists class, current smoking status, diabetes, mode of anesthesia, admission type, the number of sites contoured, and operative time. Given the proposed theoretical relationship between liposuction volume and body mass index, an interaction term for this association was included in the regression models. An interaction term quantifies how changes in the marginal effect of one variable is conditioned by changes in another variable's value; in this case, how the risk incurred by increasing liposuction volume is affected by changes in body mass index.[35,36] The β value for body mass index, liposuction volume, and the interaction term were used to develop a spreadsheet that returns a single odds ratio for any combination of body mass index and liposuction volume. Hosmer-Lemeshow and C statistics were calculated for each logistic regression and demonstrated adequate goodness of fit and discriminatory capability, respectively.[37]

Recursive partitioning has been described extensively and was used to determine a threshold of liposuction volume per unit body mass index that resulted in a significantly greater risk of complication.[38–41] A 10-fold cross-validation was used to assess the predictive ability of the model. The independent predictive value of this threshold on the likelihood of overall complications was evaluated using multivariate logistic regression analysis.

RESULTS

Patient Demographics

Overall, 4534 patients who underwent liposuction were included in our analysis, with a total of 69 patients (1.5 percent) experiencing at least one postoperative complication. These patients underwent liposuction with an average volume of 2.1 ± 1.8 liters and had an average body mass index of 26.5 ± 4.5 kg/m^2. Patient demographic data and operative characteristics of the total cohort are delineated in Table 1. Patients who experienced one or more complications underwent procedures with higher average liposuction volumes (3.4 ± 2.7 liters versus 2.1 ± 2.7 liters; $p < 0.001$) and had higher body mass indexes (28.2 ± 4.3 kg/m^2 versus 26.5 ± 4.5 kg/m^2; $p = 0.003$) than patients who did not experience a complication (Table 2).

Unadjusted Outcomes

A complete record of complications for the study cohort is shown in Table 3. The rate of medical ($p = 0.999$) and hospital return ($p = 0.999$) complications did not differ significantly between the large-volume and non–large-volume liposuction groups (Table 4). Patients undergoing large-volume liposuction did, however, experience more overall (3.7 percent versus 1.4 percent; $p = 0.001$) and surgical complications (3.7 percent versus 1.1 percent; $p < 0.001$), attributable almost entirely to the higher rate of seroma (3.1 percent versus 0.8 percent; $p < 0.001$).

Adjusted Outcomes

Although both increasing liposuction volumes (OR, 1.37; 95 percent CI, 1.14 to 1.65; $p < 0.001$)

Table 1. Patient Demographics and Operative Characteristics of the Study Cohort*

Characteristic	Value (%)
No. of patients	4534
Liposuction volume, liters	2.14 ± 1.80
Age, yr	41.55 ± 11.78
Body mass index, kg/m^2	26.54 ± 4.47
Male	837 (18.5)
ASA physical classification ≥ 3	37 (0.8)
Current smoker	287 (6.9)
Diabetes	51 (1.2)
Outpatient procedure	4462 (98.6)
Mode of anesthesia	
General anesthesia	2859 (65.3)
MAC or conscious sedation	872 (19.9)
Local anesthesia	648 (14.8)
Operative time, min	106.3 ± 63.5

ASA, American Society of Anesthesiologists; MAC, monitored anesthesia care.
*Categorical variables are presented as no. (%) and continuous variables are presented as mean ± SD.

Table 2. Patient Demographics and Operative Characteristics by Complication*

	No Complications (%)	Any Complication (%)	*p*
No.	4465	69	
Liposuction volume, liters	2.1 ± 1.8	3.4 ± 2.7	<0.001†
Age, yr	41.6 ± 11.8	41.5 ± 11.9	0.977
Body mass index, kg/m²	26.5 ± 4.5	28.2 ± 4.3	0.003†
Male	819 (18.3)	18 (26.1)	0.100
ASA physical classification ≥ 3	35 (0.8)	2 (3.0)	0.109
Current smoker	282 (6.9)	5 (7.5)	0.806
Diabetes	50 (1.2)	1 (1.5)	0.572
Outpatient procedure	4395 (98.6)	67 (98.5)	0.623
Mode of anesthesia			0.011†
General anesthesia	2820 (65.4)	39 (57.4)	
MAC or conscious sedation	849 (19.7)	23 (33.8)	
Local anesthesia	642 (14.9)	6 (8.8)	
No. of sites contoured			0.855
1	4317 (96.7)	68 (98.6)	
2	138 (3.1)	1 (1.4)	
3	9 (0.2)	0 (0.0)	
4	1 (0.1)	0 (0.0)	
Operative time, min	105.5 ± 63.02	156.4 ± 75.5	<0.001†

ASA, American Society of Anesthesiologists; MAC, monitored anesthesia care.
*Categorical variables are presented as no. (%) and continuous variables are presented as mean ± SD.
†Denotes statistical significance ($p < 0.05$).

Table 3. Outcomes and Complications of the Study Cohort

Complications	No. (%)
Overall complications*	69 (1.5)
Surgical complications*	60 (1.3)
Seroma requiring drainage	43 (0.9)
Hematoma requiring drainage	5 (0.1)
Operative infection*	10 (0.2)
Superficial SSI	7 (0.2)
Deep SSI	3 (0.1)
Medical complications*	5 (0.1)
Venous thromboembolism*	1 (0.1)
Deep vein thrombosis	1 (0.1)
Pulmonary embolism	0 (0.0)
Cardiac complication	0 (0.0)
Neurologic complication	1 (0.1)
Respiratory complication	1 (0.1)
Renal/genitourinary complication	1 (0.1)
Bleeding complication	1 (0.1)
≤4 units	0 (0.0)
>4 units	1 (0.1)
Any return to the hospital*	11 (0.2)
Unplanned ER visit	6 (0.1)
Unplanned readmission	2 (0.1)
Return to the operating room	5 (0.1)
Death	0 (0.0)

SSI, surgical-site infection; ER, emergency room.
*Patients may have more than one complication.

and body mass index (OR, 1.11; 95 percent CI, 1.01 to 1.23; $p = 0.039$) independently increased the risk for complications, their combined interaction demonstrated a decrease in overall complications when each 250-ml increase in lipoaspirate volume was accompanied by a simultaneous unit increase in body mass index (OR, 0.99; 95 percent CI, 0.98 to 0.99; $p = 0.007$). Figure 1 graphically illustrates the effect of varying lipoaspirate volumes and body mass index on the adjusted odds ratio for overall complications compared with a reference patient with a body mass index of 15 and a lipoaspirate volume of 0. The full results of our logistic regression models are available in Table 5. Of note, similar interaction effects between liposuction volume and body mass index were observed when complications were stratified by surgical complications and seroma.

Recursive partitioning identified a liposuction volume per body mass index unit in excess of 103.8 ml per unit of body mass index (in kilograms per meter squared) as the threshold where overall complications increased significantly (2.9 percent versus 0.9 percent; $p < 0.001$). This threshold was a significant independent predictor of overall complications (OR, 4.65; 95 percent CI, 2.66 to 8.14; $p < 0.001$). To obtain a more clinically useful threshold for liposuction volumes, a threshold of 100 ml per unit of body mass index was evaluated and shown to be a predictor for overall complications, surgical complications, seroma, and operative infection (Tables 6 and 7).

DISCUSSION

Advances in technique and a greater understanding of the physiologic fluid dynamics governing liposuction have allowed increasing volumes of lipoaspirate to be removed during a single surgical procedure. Despite these advances, no safe upper limit of total lipoaspirate volume has been elucidated. Instead, current patient safety advisories advise surgeons to formulate an overall impression of surgical risk based on patient body mass index and comorbidity burden.[25] Such estimates are intrinsically subjective, preventing a precise quantification of risk to guide surgeon and patient decision-making. This study is the first attempt at identifying the risk of complications conferred by varying liposuction volumes.

Our study confirmed the safety of liposuction, with an overall complication rate of 1.5 percent, the majority of which were minor complications. The incidence of a postoperative hospital visit (0.2 percent) and reoperation were low (0.1 percent), as was the overall incidence of venous thromboembolism (0.1 percent). In addition, the incidence of cardiac (0.0 percent), neurologic (0.1 percent),

Table 4. Outcomes and Complications by Liposuction Volume

	Non–Large-Volume Liposuction (≤5000 ml) (%)	Large-Volume Liposuction (>5000 ml) (%)	*p*
No.	4210	324	
Overall complications*	57 (1.4)	12 (3.7)	0.001†
Surgical complications*	48 (1.1)	12 (3.7)	<0.001†
Seroma requiring drainage	33 (0.8)	10 (3.1)	<0.001†
Hematoma requiring drainage	5 (0.1)	0 (0.0)	0.999
Operative infection*	9 (0.2)	1 (0.3)	0.524
Superficial SSI	7 (0.2)	0 (0.0)	0.999
Deep SSI	2 (0.1)	1 (0.3)	0.199
Medical complications*	5 (0.1)	0 (0.0)	0.999
Venous thromboembolism*	1 (0.1)	0 (0. 0)	0.999
Deep vein thrombosis	1 (0.1)	0 (0.00)	0.999
Pulmonary embolism	0 (0.0)	0 (0.0)	0.999
Cardiac complication	0 (0.0)	0 (0.0)	0.999
Neurologic complication	1 (0.1)	0 (0.0)	0.999
Respiratory complication	1 (0.1)	0 (0.0)	0.999
Renal/genitourinary complication	1 (0.1)	0 (0.0)	0.999
Bleeding complication	1 (0.1)	0 (0.00)	0.999
≤4 units	0 (0.0)	0 (0.0)	0.999
>4 units	1 (0.02)	0 (0.0)	0.999
Any return to the hospital*	11 (0.3)	0 (0.0)	0.999
Unplanned ER visit	6 (0.1)	0 (0.0)	0.999
Unplanned readmission	2 (0.1)	0 (0.0)	0.999
Return to the operating room	5 (0.1)	0 (0.0)	0.999
Death	0 (0.00)	0 (0.00)	0.999

SSI, surgical-site infection; ER, emergency room.
*Patients may have more than one complication.
†Denotes statistical significance ($p < 0.05$).

and respiratory (0.1 percent) complications that may result from volume overload and lidocaine toxicity were low and did not differ between non–large-volume and large-volume liposuction cohorts. Moreover, there were no deaths within the study cohort. The results of our analysis of the Tracking Operations and Outcomes for Plastic Surgeons database corroborates reports of several previous

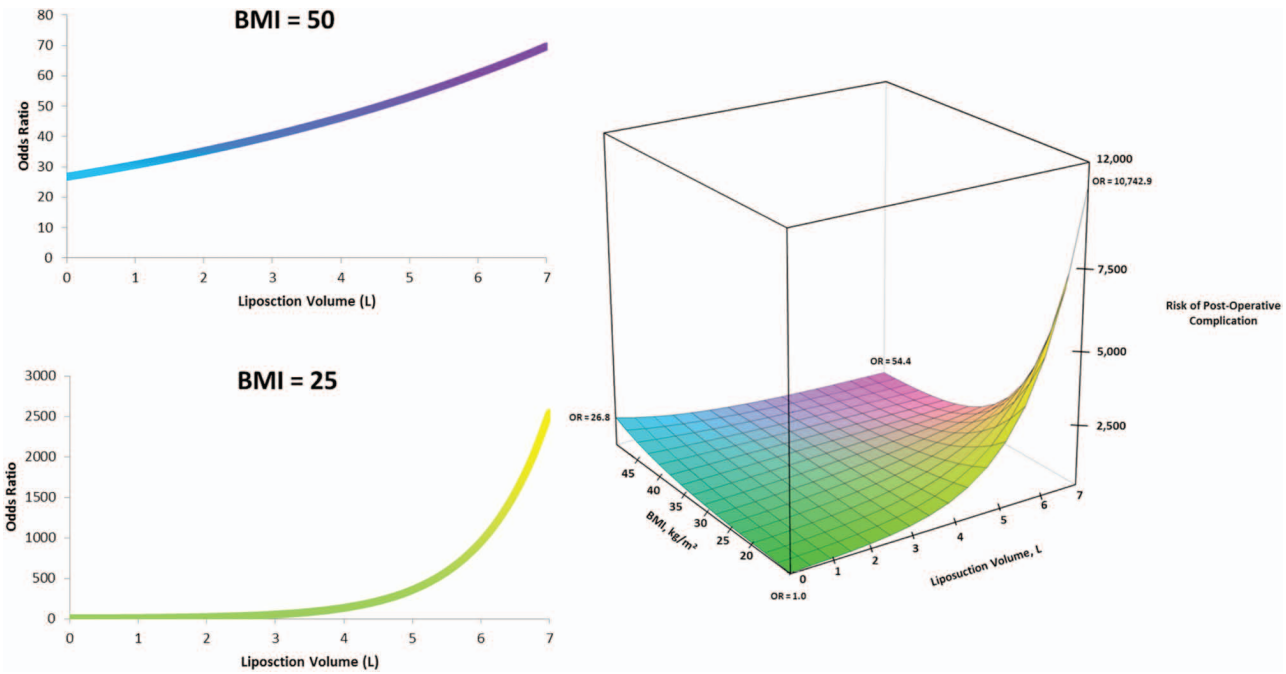

Fig. 1. Three-dimensional representation of adjusted odds ratios for overall complications based on liposuction volume and body mass index (*BMI*) with representative risk curves for patients with a body mass index of 25 or 50. Adjusted odds ratios were derived with respect to a reference patient with a body mass index of 15 and a lipoaspirate volume of 0.

Table 5. Results of Multivariate Logistic Regressions

Variable	OR	95% CI	*p*
Overall complications*			
Liposuction volume 250 ml‡	1.37	1.14–1.65	0.001†
BMI	1.11	1.01–1.23	0.039†
Interaction effect between liposuction volume and BMI	0.99	0.98–0.99	0.007†
Surgical complications*			
Liposuction volume 250 ml‡	1.48	1.21–1.81	<0.001†
BMI	1.15	1.03–1.28	0.012†
Interaction effect between liposuction volume and BMI	0.99	0.98–0.99	0.002†
Medical complications*			
Liposuction volume 250 ml‡	1.07	0.49–2.07	0.984
BMI	1.09	0.98–1.21	0.103
Interaction effect between liposuction volume and BMI	0.99	0.98–1.02	0.999
Seroma			
Liposuction volume 250 ml‡	1.53	1.23–1.91	<0.001†
BMI	1.14	1.01–1.29	0.040†
Interaction effect between liposuction volume and BMI	0.98	0.98–0.99	0.002†
Hematoma			
Liposuction volume 250 ml‡	0.98	0.12–7.68	0.981
BMI	0.70	0.25–1.97	0.496
Interaction effect between liposuction volume and BMI	1.00	0.91–1.10	0.977
Operative infection*			
Liposuction volume 250 ml‡	1.26	0.70–2.27	0.447
BMI	1.10	0.79–1.54	0.557
Interaction effect between liposuction volume and BMI	0.99	0.97–1.01	0.529
Return to hospital*			
Liposuction volume 250 ml‡	1.08	0.57–2.07	0.814
BMI	1.08	0.79–1.47	0.652
Interaction effect between liposuction volume and BMI	1.00	0.97–1.02	0.776

BMI, body mass index.
*Patients may have more than one complication. Other variables included in multivariate logistic regression models included age, sex, American Society of Anesthesiologists physical status classification, current smoking status, diabetes, mode of anesthesia, number of body sites contoured, and operative time.
†Denotes statistical significance ($p < 0.05$).
‡Increase in odds ratio is per 250 ml of lipoaspirate.

publications that demonstrate the favorable complication profile of liposuction.[9–12] It is important to note that the American Society of Plastic Surgeons Safety Committee has recommended that patients who undergo large-volume liposuction should be observed overnight in the inpatient setting for close postoperative monitoring of potential fluid and electrolyte imbalances.[9,22,42] Despite this, over 97 percent of the large-volume liposuction procedures in our cohort were performed in the outpatient setting, with no significant differences in medical complications (0.1 percent versus 0.0 percent; $p = 0.999$). The lack of morbidity associated with performing the procedure on an outpatient basis is possibly indicative of the success of current fluid resuscitation strategies with large-volume reductions.[8,22]

Despite the overall safety of liposuction, the need for evidence-based safety profiles for lipoaspirate volume became more apparent in the wake of several highly publicized reports of patient deaths following liposuction.[24,43,44] As a result, several states have imposed legislative restrictions on aspirate volumes, mainly when liposuction is combined with other procedures, with limits on outpatient procedures ranging from 1000 to 5000 ml.[25,45,46] In response to the increased scrutiny by state legislative and regulatory bodies and in an effort to curtail complications following liposuction, the American Society of Plastic Surgeons convened the Patient Safety Committee, which adopted the position that a total aspirate volume greater than 5000 ml is an important safety marker necessitating overnight admission with careful perioperative monitoring of vital signs and urinary output.[24,25] Our study showed no difference in major complications between the non–large-volume (≤5000 ml) and large-volume (>5000 ml) liposuction cohorts. The only statistically significant difference between cohorts was the seroma rate, which was higher in the large-volume liposuction group.

The question is then raised: Do current guidelines specifying 5000 ml as an important safety threshold actually predict an increased procedural risk? The results of our bivariate analysis seem to indicate the answer is no. Our results instead suggest that complications are not wholly dependent on the absolute volume of lipoaspirate, but rather include the synergistic effects of other relevant patient factors, namely, body mass index. Both higher lipoaspirate volume and body

Table 6. Effect of a Recursive Partitioning Analysis Generated Threshold of Liposuction Volume per Body Mass Index Unit on the Likelihood of Overall Complications: Differences between Groups Generated by Recursive Partitioning

	Liposuction Volume		
	<100 ml/BMI Unit (%)	>100 ml/BMI Unit (%)	*p*
No.	2734	1280	
Overall complications*	24 (0.88)	45 (3.52)	<0.001†
Surgical complications*	19 (0.69)	41 (3.20)	<0.001†
Seroma requiring drainage	14 (0.51)	29 (2.27)	<0.001†
Hematoma requiring drainage	2 (0.07)	3 (0.23)	0.335
Operative infection*	2 (0.07)	8 (0.63)	0.002†
Superficial SSI	1 (0.04)	6 (0.47)	0.005†
Deep SSI	1 (0.04)	2 (0.16)	0.240
Medical complications*	2 (0.07)	3 (0.23)	0.335
Venous thromboembolism*	0 (0.00)	1 (0.08)	0.319
Deep vein thrombosis	0 (0.00)	1 (0.08)	0.319
Pulmonary embolism	0 (0.00)	0 (0.00)	0.999
Cardiac complication	0 (0.00)	0 (0.00)	0.999
Neurologic complication	1 (0.04)	0 (0.00)	0.999
Respiratory complication	1 (0.04)	0 (0.00)	0.999
Renal/genitourinary complication	0 (0.00)	1 (0.08)	0.319
Bleeding complication	0 (0.00)	1 (0.08)	0.319
≤4 units	0 (0.00)	0 (0.00)	0.999
>4 units	0 (0.00)	1 (0.08)	0.319
Any return to the hospital*	4 (0.15)	7 (0.55)	0.045†
Unplanned ER visit	3 (0.11)	3 (0.23)	0.391
Unplanned readmission	1 (0.04)	4 (0.31)	0.038†
Return to the operating room	2 (0.07)	0 (0.00)	0.999

BMI, body mass index; SSI, surgical-site infection; ER, emergency room.
*Patients may have more than one complication. Other variables included in multivariate logistic regression models include age, sex, American Society of Anesthesiologists physical status classification, current smoking status, diabetes, mode of anesthesia, number of body sites contoured, and operative time.
†Denotes statistical significance ($p < 0.05$).

mass index increase the odds of overall complications independently, but when both variables are increased simultaneously, a small protective effect is observed. In other words, obese patients may tolerate larger lipoaspirate volumes without an increased risk of complications compared with low–body mass index individuals, who experience a more exponential increase in risk with increases in lipoaspirate volume. This challenges the conventional wisdom that there exists an *absolute* threshold for safety in liposuction procedures, suggesting that it is actually the *relative* volume of lipoaspirate that is pertinent when considering surgical risk. For example, when considering two patients desiring large-volume lipoplasty, one with a body mass index of 30 and the other with a body mass index of 50, a surgeon relying on traditional promulgated threshold limits may assume that the risk of removing a given lipoaspirate volume is the same for both patients. Even when body mass index is considered as a risk factor, surgeons may inaccurately estimate the individual's net risk given the intricate interdependence of body mass index and liposuction volume. We have constructed an odds ratio calculator to demonstrate this precise effect. In a patient with a body mass index of 30, increasing the lipoaspirate volume from 2 liters to 6 liters results in a nearly 25-fold increase in the likelihood of a complication, reflected by an increase in the adjusted odds ratio of any complication from 20.3 to 500.7 (Fig. 2). Conversely, in the patient with a body mass index of 50, the same increase in lipoaspirate volume results in a modest increase in the risk of an overall complication from 32.9 to

Table 7. Effect of a Recursive Partitioning Analysis Generated Threshold of Liposuction Volume per Body Mass Index Unit on the Likelihood of Overall Complications: Multivariate Logistic Regression Evaluating Proposed Threshold of 100 ml per Body Mass Index Unit as an Independent Predictor for Complications

	OR	95% CI	*p*
Overall complications*	4.58	2.60–8.05	<0.001†
Surgical complications*	5.45	2.94–10.09	<0.001†
Seroma	4.87	2.42–9.80	<0.001†
Operative infection*	7.03	1.42–34.69	0.017†
Any return to the hospital*	4.05	1.00–16.50	0.051

*Patients may have more than one complication. Other variables included in multivariate logistic regression models include age, sex, American Society of Anesthesiologists physical status classification, current smoking status, diabetes, mode of anesthesia, number of body sites contoured, and operative time.
†Denotes statistical significance ($p < 0.05$).

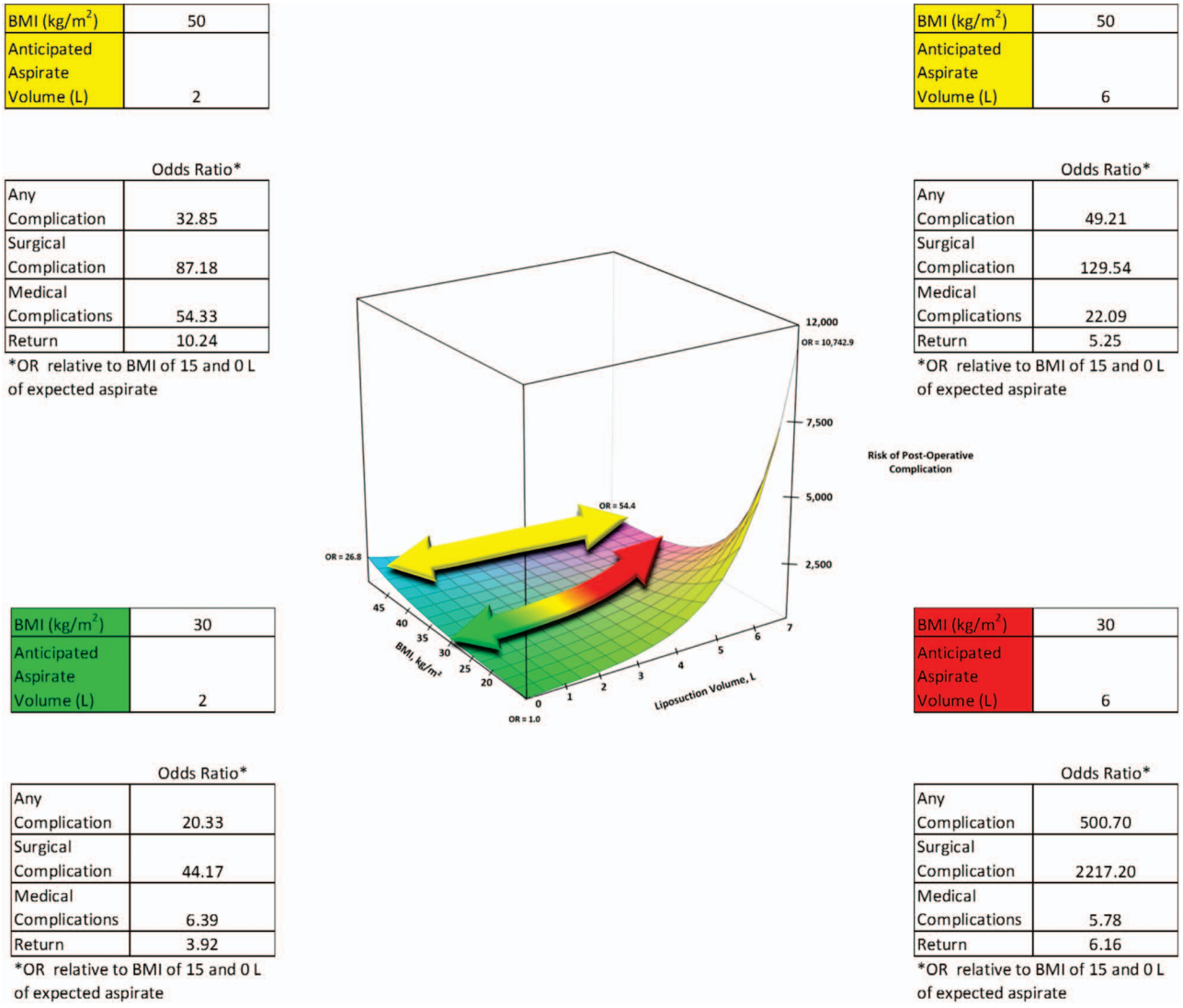

Fig. 2. Risk of liposuction in a morbidly obese patient and an obese patient, with representative risk curves for each patient. Adjusted odds ratio for overall complications in a high–body mass index (*BMI*) patient undergoing low- (*above*, *left*) and high-volume (*above*, *right*) liposuction. Adjusted odds ratio for a low–body mass index patient undergoing low- (*below*, *left)* and high-volume (*below*, *right*) liposuction. Three-dimensional representation of adjusted odds ratios demonstrating the protective effect of increasing body mass index on increasing liposuction volumes. *Arrows* represent risk profiles for low– and high–body mass index patients (*center*). Adjusted odds ratios were derived with respect to a reference patient with a body mass index of 15 and a lipoaspirate volume of 0.

49.2 (Fig. 2). These two hypothetical patients demonstrate the important nonlinear nature of the relationship between body mass index and liposuction volume. Instead, the two variables serve as buffers whereby an increase in liposuction volume in a patient with a lower body mass index results in a far greater magnitude of increased risk than in a patient with a higher body mass index.

Previous investigators have attempted to identify volumetric limits based on body mass. Current opinion is that that ideal liposuction candidates are within 20 to 30 percent of their ideal body weight.[20,47,48] Although this philosophy has been widely disseminated in the evaluation of liposuction candidates, the basis for this recommendation and its effect on outcomes has never been explored. Moreover, these restrictions ignore the dynamic relationship between body mass index and lipoaspirate volume. In an effort to account for both of these factors, a single surgeon critically appraised all cases of death and nonfatal complications in his practice following liposuction, leading him to suggest that the amount of fat removed during liposuction should not exceed 6 to 8 percent of the patient's body weight and 30 percent of the patient's body surface area.[49] Although this suggestion more accurately reflects the effect of both liposuction volume and body mass index, it was ultimately based on the observations of

a single surgeon without quantifying the risks associated with exceeding this proposed cutoff. Thus, we sought to generate a liposuction volume threshold with a quantifiable effect on outcomes and that accounts for the dynamic relationship between liposuction volumes and body mass index. Our analysis suggests that a liposuction volume in excess of 100 ml per body mass index unit represented the point along the risk continuum where risk begins to increase in a more exponential fashion and was independently predictive of complications. For instance, the procedural risk for a patient with a body mass index of 30 increases significantly when more than 3000 ml of aspirate is removed, whereas in a patient with a body mass index of 50, the calculated safety threshold is 5000 ml. Such a threshold better estimates risk than current recommendations and is eminently translatable, enabling surgeons to easily calculate a practical and individualized safety cutoff that is more predictive of postoperative complications. Ultimately, no guideline can serve as a replacement for an individual surgeon's clinical decision-making ability. Although our findings can be readily applied to patients across a broad range of body mass indexes and lipoaspirate volumes, they are by no means comprehensive. The likelihood of a complication may not be adequately captured at extremes of either value. Our model also does not account for extenuating factors that may be more relevant to a specific patient's individualized risk for a complication.

This study is not without limitations, some of which stem from Tracking Operations and Outcomes for Plastic Surgeons program's data collection methodologies. The inability to define the specific nature of the liposuction procedure performed (e.g., traditional, power-assisted, ultrasonic) is of particular significance. Complications after liposuction have been shown to be dependent on operative technique and the choice of wetting solution.[50–52] This limitation prohibits an accurate estimation of risk in patients undergoing different methods of liposuction. There is also concern over the self-reported nature of program's data, although our 30-day complication rates were similar to those reported in studies using other national registries.[53] When compared with other validated registries, the Tracking Operations and Outcomes for Plastic Surgeons database has been shown to accurately capture outcomes, including those with specific relevance to the plastic surgical community, across both private practice and academic settings.[34]

Finally, the cutoff derived in this model represents the first attempt at generating an evidence-based volumetric limit for liposuction. It is important to note that our findings apply almost exclusively to minor complications; the incidence of potentially life-threatening complications was less than 0.1 percent. As such, this serves as an initial proof of concept for the derivation of more individualized risk assessment tools for liposuction volumes. The primary measure of interest in our study was lipoaspirate volume because regulatory agencies have identified this factor as the primary adjudicator of surgical risk despite minimal evidence for this claim. Ideally, further studies with more granular data will help to refine and validate this guideline while also assessing whether other measures may serve as a better proxy for liposuction risk.

CONCLUSIONS

Liposuction performed by board-certified plastic surgeons is safe, with an exceedingly low risk of life-threatening complications. Traditional liposuction volume thresholds do not accurately convey individualized risk. By incorporating body mass index, we demonstrate that liposuction volumes in excess of 100 ml per unit of body mass index confer an increased risk of complications.

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