IMPACT OF BODY MASS INDEX AND ALBUMIN ON MORBIDITY AND MORTALITY AFTER CARDIAC SURGERY

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Objective: Extremely thin and overly obese patients may not tolerate cardiac surgery as well as other patients. A retrospective study was conducted to determine whether the extremes of body mass index (weight/height^2 [kg/m^2]) and/or cachexia increased the morbidity and mortality associated with cardiac operations. **Methods:** Body mass index was used to objectively measure "thinness" (body mass index < 20) and "heaviness" (body mass index > 30); preoperative serum albumin was used to quantify nutritional status and underlying disease. Data were gathered between 1993 and 1997 from 5168 consecutive patients undergoing coronary artery bypass or valve operations, or both. **Results:** No significant correlations were observed between body mass index and preoperative albumin levels. Low body mass index (<20) and low albumin level (<2.5 g/dL) were each independently associated with increased mortality after cardiopulmonary bypass ($P \leq .0005$). Operative mortality was highest among those with both low body mass index and low albumin level. Multivariable logistic regression, adjusting for potentially confounding variables, demonstrated that an albumin level of less than 2.5 g/dL was independently associated with increased risk of reoperation for bleeding, postoperative renal failure, and prolonged ventilatory support, intensive care unit stay, and total length of stay. A body mass index of more than 30 was associated with increased sternal wound infection and saphenous vein harvest site infection. **Conclusions:** Hypoalbuminemia and low body mass index each independently predict increased morbidity and mortality after cardiac operations. Preoperative risk stratification with the use of body mass index and serum albumin may help to identify subgroups of patients at high risk for adverse outcomes after cardiac operations. (J Thorac Cardiovasc Surg 1999;118:866-73)

It is widely assumed that obese patients have a significantly increased risk for major complications after cardiac operations. However, recent studies have shown no significant association between obesity and major cardiac surgical morbidity and mortality.^{1,2} A study by

Loop and associates³ suggested that thin patients may actually be at a higher risk after coronary artery operations. The effect of small body size on the incidence of complications, length of stay, and mortality after cardiac operations has not been extensively studied. We used prospectively collected data compiled on 5168 consecutive patients undergoing cardiac operations at Brigham and Women's Hospital from January 1993 to December 1997 to assess the independent contribution of body size to morbidity and mortality after cardiac operations.

Malnutrition has also been reported to increase the morbidity and mortality after cardiac operations.⁴ One objective measure of malnutrition is serum albumin. Preoperative serum albumin levels have been found to be strong independent predictors of morbidity and mortality in a recent large study of patients undergoing non-

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cardiac surgery.⁵ We used the preoperative serum albumin level to determine the degree to which hypoalbuminemia contributed to postoperative morbidity and mortality. In addition, we assessed whether any association between body mass index (BMI) and surgical outcome was dependent on the preoperative nutritional status as measured by serum albumin.

Patients and methods

Data were collected prospectively from 5168 consecutive patients undergoing coronary artery bypass grafting (CABG) or valve surgery, or both, at Brigham and Women's Hospital between 1993 and 1997. Patients with other concomitant surgical procedures were excluded from the study (eg, carotid endarterectomy, aortic procedures, transplantation, transmyocardial laser procedures, and congenital abnormalities). Patients undergoing primary as well as reoperative surgery were included in the study. The degree of thinness or obesity was assessed by the BMI.⁶ The BMI is defined as the weight in kilograms divided by the height in meters squared. Of the obesity indexes, BMI correlates least with height and most with more direct measurements of percent body fat.⁷ A BMI of less than 20 was defined as our high-risk thin group. This corresponds to a weight more than 25% below the ideal body weight for an individual height.⁸ A BMI of more than 30 was defined as our high-risk obese group. This corresponds to 1 standard deviation above the mean BMI.¹ Preoperative serum albumin was collected from all patients.

All operations were performed with systemic hypothermia (30°C) and cold blood cardioplegia. Intraoperative transesophageal and epiaortic ultrasound (or both) was used in patients selectively. Cardiopulmonary bypass flow rates were between 1.8 and 2.0 L · min⁻¹ · m⁻², and mean arterial pressure was maintained between 40 and 80 mm Hg. Patients with known cerebrovascular disease were maintained at the higher end of this pressure spectrum. Proximal and distal anastomoses were performed in the majority of CABG cases by means of a single crossclamping technique.

Postoperative neurologic events were verified by computed tomographic scanning and a neurologic consultation and included both transient ischemic attacks and strokes. A low cardiac output state was defined as the need for an intra-aortic balloon pump or inotropic agents to keep the cardiac index more than 2.0 L · min⁻¹ · m⁻² for greater than 24 hours after the operation. Operative mortality was defined as death during the initial hospitalization or within 30 days of the operation.

Statistical analysis. The χ^2 test was used to evaluate potential confounders of the relationship between low serum albumin or the extremes of BMI and operative morbidity and mortality. A variable was considered a potential confounder if it was related to albumin or BMI and operative death or complication with a *P* value $\leq .20$.

To adjust for the potential confounding effects of other risk factors, we used multivariable logistic regression to evaluate operative mortality and morbidity risk associated with low albumin levels and the extremes of BMI. The potential con-

Table I. Percent operative mortality and number of patients in each group (*n*) in strata of BMI and preoperative serum albumin

	BMI (kg/m ²)			All patients
	<20	20-30	>30	
Albumin (g/dL)				
< 2.5	16 (49)	7 (589)	8 (130)	7 (768)
2.5-3.5	9 (81)	3 (1365)	5 (464)	4 (1910)
> 3.5	7 (107)	3 (1777)	3 (606)	3 (2490)
All patients	10 (237)	3 (3731)	4 (1200)	4 (5168)

BMI, Body mass index.

founders included age, sex, ejection fraction, New York Heart Association functional class, previous cardiac operation, preoperative diabetes, peripheral and cerebral vascular disease, hypertension, renal failure, congestive heart failure, myocardial infarction, chronic obstructive pulmonary disease, smoking, urgency of operation, use of an internal thoracic artery, and type of operation. The odds ratio for mortality for each of the identified risk factors was then calculated.⁹ We also fit multivariable models with albumin as a continuous variable and with BMI expressed with linear and then cubic splines.^{10,11} Goodness of fit was assessed with the Hosmer and Lemeshow goodness-of-fit χ^2 test and by plotting the Hosmer and Lemeshow $\Delta \chi^2$ and Δ -D influence statistics and leverage against the predicted probability of death or morbidity.¹² The statistical analyses were performed with the use of Stata version 5 (Stata Corporation, College Station, Tex).

Results

Sixty-eight percent of the patients underwent isolated CABG procedures, 18% underwent isolated valve operations, and 14% underwent combined CABG/valve procedures. The median age of the patients was 67 years with a lower quartile of 59 years and an upper quartile of 74 years. The median BMI was 26.6 with a lower quartile of 23.9 and an upper quartile of 29.7. The median serum albumin level was 3.5 g/dL with a lower quartile of 2.7 g/dL and an upper quartile of 4.1 g/dL.

The overall mortality was 3.8%. Table I shows the percent mortality in strata of BMI and preoperative serum albumin. Low BMI (<20) and low albumin level (<2.5 g/dL) were each associated with increased mortality after cardiopulmonary bypass (*P* $\leq .0005$). Those with both low BMIs and low albumin levels had the highest mortality (16%). At all levels of BMI the operative mortality was higher among patients with an albumin level less than 2.5 g/dL. At all levels of albumin the operative mortality was higher in those with a BMI less than 20 (Table I). Patients with extremely high BMIs

Table II. Patient profile: Percent of patients in strata of albumin, body surface area, and operative outcome who had the characteristics on the left (column percentages)

	Albumin (g/dL)			BMI (kg/m ²)			All patients	Operative death	
	< 2.5	2.5-3.5	> 3.5	< 20	20-30	>30		Yes	No
No. of patients	768	1910	2490	237	3731	1200	5168	196	4972
Percent of all patients	15	37	48	5	72	23	100	3.8	96.2
Demographics:									
Percent female	40	32	30	60	29	36	32	42	31
Percent age > 75 y	27	23	23	42	25	16	25	40	23
BMI (kg/m ²)									
Percent thin (<20)	6	5	4				5	12	4
Percent 20-30	77	73	71				72	65	73
Percent obese (> 30)	17	22	25				23	23	23
Low serum albumin (g/dL)									
Percent < 2.5				21	16	11	15	29	14
Percent 2.5-3.5				21	20	19	37	16	20
Percent > 3.5				58	64	70	48	55	66
Risk factors:									
Percent EF < 30%	7	7	8	14	7	6	7	16	7
Percent NYHA functional class IV	21	17	17	20	18	16	18	36	17
Percent previous cardiac surgery	17	16	16	23	16	14	16	36	15
Percent diabetes	30	26	28	16	24	40	28	34	27
Percent PVD	17	13	11	16	13	11	13	29	12
Percent cerebral vascular disease	16	12	10	15	12	9	11	23	11
Percent hypertension	61	60	57	44	57	66	58	70	58
Percent renal failure	12	10	8	15	9	8	9	22	9
Percent CHF	40	32	35	61	34	32	35	57	34
Percent previous MI	55	51	47	37	49	52	49	67	49
Percent COPD	11	10	10	17	10	11	10	15	10
Percent smoking history	63	64	64	58	63	67	64	64	64
Clinical presentation:									
Percent elective operation	58	66	70	63	67	67	67	41	68
Percent emergency/urgent operation	42	34	30	37	33	33	33	59	32
Intraoperative procedure:									
Percent CABG	68	67	67	36	67	77	68	52	68
Percent valve	14	16	19	37	19	11	18	14	18
Percent CABG/valve	17	15	14	27	14	12	14	34	14
Percent ITA usage	73	77	82	58	79	80	79	49	80
Percent median pump time (>120 min)	34	28	29	41	30	27	30	68	21
Percent median crossclamp time (>90 min)	30	26	24	37	25	23	25	47	24

BMI, Body mass index; EF, ejection fraction; NYHA, New York Heart Association; PVD, peripheral vascular disease; CHF, congestive heart failure; MI, myocardial infarction; COPD, chronic obstructive pulmonary disease; CABG, coronary artery bypass grafting; ITA, internal thoracic artery. Cerebral vascular disease includes any patient with a previous cerebral vascular accident, transient ischemic attack, or carotid stenosis. Peripheral vascular disease: defined by a history of claudication or prior peripheral bypass for occlusive arterial disease.

(>35) had a mortality of 4.7%, not significantly different than the referent group ($P = .16$).

The preoperative demographics, risk factors, and clinical presentation of the study group are presented in Table II. Emergency/urgent operations were performed within 24 hours of disease diagnosis. Women constituted the largest percentage of patients with a BMI less than 20 (60%). In patients who underwent CABG or CABG/valve procedures, there was no difference in

internal thoracic artery usage between patients with a BMI of 20 to 30 and those with a BMI of more than 30. Patients with a serum albumin level of less than 2.5 g/dL and a BMI of less than 20 had a greater number of comorbidities and risk factors.

Lower levels of serum albumin were associated with a higher incidence of postoperative complications and greater lengths of stay (Table III). The highest prevalence of complications was seen in those patients with

Table III. Percent of patients in strata of preoperative albumin and BMI with postoperative outcomes after CABG and/or valve surgery (column percentages)

Outcome	Albumin (g/dL)				BMI (kg/m ²)			
	<2.5	2.5-3.5	>3.5	P value*	<20	20-30	>30	P value*
CVA/TIA	5.2	3.5	3.9	.11	9.1	3.8	3.3	≤.0005
Renal failure	6.3	4.8	2.1	≤.0005	8.6	3.5	3.3	≤.0005
Pneumonia	4.3	3.8	2.8	.07	8.6	3.0	3.6	≤.0005
Sepsis	3.5	2.9	2.2	.11	3.7	2.6	2.5	.55
Myocardial infarction	4.3	2.8	2.4	.02	3.3	2.6	3.3	.41
Low cardiac output	14.7	10.4	7.6	≤.0005	16	9.4	9.6	.003
New atrial fibrillation	34	32	27	≤.0005	32	29	30	.50
Re-exploration for bleeding	7.4	4.0	4.4	.001	11.5	5.0	2.7	≤.0005
Deep sternal wound infection	3.3	3.3	2.0	.06	0.7	1.7	4.9	≤.0005
Leg infection	4.4	4.1	3.8	.83	4.6	2.8	7.0	≤.0005
ICU > 3 days	27	20	14	≤.0005	31	18	17	≤.0005
Ventilatory support > 1 day	33	23	14	≤.0005	32	19	20	≤.0005
Length of stay > 10 days	29	24	15	≤.0005	34	20	19	≤.0005

CVA, Cerebrovascular accident; TIA, transient ischemic attack; ICU, intensive care unit.

*The χ^2 test was used to calculate the P values.

Table IV. Odds ratio and 95% confidence interval for postoperative outcomes after adjustment for confounders in patients with low serum albumin or low/high BMI

Outcome	Albumin (g/dL)				BMI (kg/m ²)			
	<2.5		2.5-3.5		<20		>30	
	OR (CI)	P value	OR (CI)	P value	OR (CI)	P value	OR (CI)	P value
Death	2.0 (1.3-3.0)	.002	1.1 (0.8-1.6)	.6	2.0 (1.2-3.6)	.009	1.4 (0.9-2.1)	.1
CVA/TIA	1.1 (0.7-1.6)	.7	0.8 (0.5-1.1)	.1	1.7 (1.0-2.9)	.03	0.9 (0.6-1.4)	.7
Renal failure	2.0 (1.3-3.2)	.002	1.9 (1.3-2.7)	.001	2.0 (1.2-3.5)	.01	1.1 (0.7-1.6)	.7
Pneumonia	1.1 (0.7-1.8)	.6	1.1 (0.8-1.5)	.7	2.2 (1.3-3.8)	.003	1.4 (0.9-2.0)	.1
Sepsis	1.2 (0.7-2.0)	.5	1.1 (0.76-1.7)	.5	1.1 (0.5-2.3)	.8	1.0 (0.6-1.5)	.8
MI	1.5 (0.9-2.3)	.1	1.0 (0.7-1.4)	.9	1.5 (0.7-3.3)	.3	1.2 (0.8-1.8)	.3
Low cardiac output	1.6 (1.2-2.1)	.001	1.2 (1.0-1.5)	.1	1.3 (0.9-1.9)	.2	1.1 (0.9-1.4)	.5
New AF	1.4 (1.2-1.7)	.0001	1.3 (1.2-1.5)	.0001	1.0 (0.7-1.3)	.9	1.2 (1.0-1.4)	.02
Re-exploration for bleeding	1.4 (1.0-2.1)	.04	0.8 (0.6-1.1)	.3	2.1 (1.3-3.3)	.001	0.6 (0.4-0.8)	.005
Deep sternal wound infection	1.7 (0.8-3.6)	.2	1.5 (0.9-2.5)	.1	0.4 (0.1-3.0)	.4	2.4 (1.5-3.8)	.0001
Leg infection	1.1 (0.5-2.2)	.8	1.0 (0.7-1.6)	.8	2.0 (0.9-4.7)	.1	2.1 (1.4-3.1)	.0001
ICU > 3 days	1.7 (1.4-2.1)	.0001	1.3 (1.1-1.6)	.006	1.4 (1.0-1.9)	.07	1.0 (0.8-1.2)	.9
Ventilatory support > 1 day	2.5 (2.0-3.1)	.0001	1.5 (1.2-1.7)	.0001	1.3 (0.9-1.8)	.1	1.1 (1.1-1.4)	.2
Length of stay > 10 days	1.9 (1.5-2.4)	.0001	1.6 (1.3-1.8)	.0001	1.3 (0.9-1.9)	.1	1.0 (0.9-1.3)	.7

OR, Odds ratio; CI, 95% confidence interval; BMI, body mass index; CVA, cerebral vascular accident; TIA, transient ischemic attack; MI, myocardial infarction; AF, atrial fibrillation; ICU, intensive care unit. The referent groups are patients with a normal serum albumin (>3.5 g/dL) and normal BMI (20-30).

serum albumin levels less than 2.5 g/dL. There was no association between preoperative serum albumin levels and saphenous vein harvest site infections. A BMI less than 20 was also associated with an increased number of postoperative complications. Patients with BMIs of more than 30 had a significantly increased incidence of deep sternal wound infection and saphenous vein harvest site infections ($P \leq .0005$) without any increase in overall length of stay.

In multivariable analyses adjusting for potential confounders, patients with a serum albumin level less than

3.5 g/dL had a significantly increased risk for renal failure, postoperative atrial fibrillation, and increased length of stay (Table IV). Patients with a serum albumin level of less than 2.5 g/dL also had an increased risk of death, low cardiac output, and re-exploration for bleeding. Patients with a BMI less than 20 had an increased risk of death, cerebral vascular accident, transient ischemic attack, renal failure, pneumonia, and reoperation for bleeding. Patients with a BMI more than 30 had an increased risk of atrial arrhythmias, deep sternal wound infections, and saphenous vein har-

Fig 1. Odds ratios and 95% confidence intervals for mortality after cardiac operations from the multivariable model. CABG, Coronary artery bypass graft; BMI, body mass index; EF, ejection fraction; IMA, internal thoracic artery; MI, myocardial infarction; NYHA, New York Heart Association; COPD, chronic obstructive pulmonary disease.

vest site infections. Remarkably, these patients also had a significantly decreased risk of re-exploration for bleeding. These findings cannot be explained by differences in internal thoracic artery use, which was nearly identical between patients with a BMI of 20 to 30 and those with a BMI of more than 30.

The mortality results are independent of the type of surgical procedure performed. The odds ratio for mortality in the group with a BMI less than 20 was 2.8 after CABG, 3.0 after isolated valve operations, and 1.4 after combined CABG/valve procedures. The odds ratio for mortality in the group with an albumin level less than 2.5 g/dL was 1.6 after CABG, 3.2 after isolated valve operations, and 2.4 after combined CABG/valve procedures. A low serum albumin level was a better predictor of mortality in isolated valve and combined valve procedures than in isolated CABG procedures. A BMI of more than 30 or an albumin level of 2.5 to 3.5 g/dL was not associated with a significantly increased mortality in any surgical subgroup. There was no significant interaction between BMI and albumin level.

Analyzing both BMI and albumin level as continuous variables illustrated that the risk of death decreased linearly with increasing levels of albumin (odds ratio = 0.78 per albumin unit, $P = .02$). To adjust for the U-

shaped relationship between operative mortality and BMI, we have used linear splines within the ranges of less than 20, 20 to 30, and more than 30. We chose these knots after examining the relationship between operative mortality and BMI. The models provided essentially the same information as those using categories of BMI and albumin. We have presented analyses with categories of BMI and albumin in the tables and figures for ease of interpretation.

To better understand the predictive value of a low BMI or low albumin level for operative mortality relative to the other identified preoperative risk factors, each of the odds ratios are listed from the highest to the lowest value in Fig 1. A BMI less than 20 is among the factors most highly associated with mortality, with an odds ratio of 2.1 ($P = .009$). An albumin level of less than 2.5 g/dL has an odds ratio of 2.0 ($P = .002$). A BMI of more than 30 has an odds ratio of 1.3 ($P = .15$).

Discussion

The main finding in this study was that both low BMI and hypoalbuminemia independently predicted increased mortality and postoperative complications after cardiac surgery. The thinnest patients were found to have more risk factors for postoperative morbidity

and mortality. In addition, women represented a greater percentage of patients in the low BMI group than the other groups. Using multivariable analysis and adjusting for these risk factors, we found that the increased postoperative morbidity and mortality remained significant in patients with a low BMI and hypoalbuminemia.

Christakis and associates¹³ suggested a similar relationship between BMI and operative mortality/low cardiac output after isolated CABG procedures. Other studies^{3,14,15} have similarly implied that patients with smaller body surface areas have a higher mortality independent of other risk factors. Mickleborough and colleagues¹⁶ found an increased incidence of perioperative myocardial infarction and low cardiac output in patients with low body surface areas after isolated CABG, but no difference in mortality.

Multiple mechanisms likely explain the increased risk of morbidity and mortality in patients with low BMI undergoing cardiac operations. Despite our best efforts, the influences of these patients' greater number of comorbidities cannot be fully adjusted. In addition, these patients may be adversely affected by having smaller coronary arteries and receiving smaller valves. However, others have reported that there was no difference between women and men in the percentage of small distal vessels.¹⁶ Patients with a low BMI may also be more hemodiluted by a fixed bypass circuit during cardiopulmonary bypass. This may result in greater postoperative weight gain, transfusion requirements, and length of stay. Another explanation may be that patients with low BMIs (and a lower percentage of body fat) have less nutritional reserve, which may not allow them to handle complications as well, resulting in greater mortality.

In this study we found that obesity did not predict increased mortality after cardiac surgery. There was, however, an increased risk of atrial arrhythmias, deep sternal wound infections, and saphenous vein harvest site infections. Our findings are similar to those of other recent reports.^{1,2,17} Surprisingly, obesity was associated with a statistically significant reduction in risk of re-exploration for bleeding. Similar findings were reported by Birkmeyer and associates.² Our study did not take into consideration readmission rates or postdischarge complications that may have been increased in these obese individuals.

Preoperative malnutrition has been associated with poor outcome after cardiac surgery.¹⁸ Serum albumin levels have been shown to correlate with overall nutritional status.¹⁹ Rich and coworkers⁴ have shown that hypoalbuminemia predicts increased risk of perioperative complications in elderly patients after cardiac surgery. A study by Abel and colleagues²⁰ concluded

that preoperative serum albumin measurements did not correlate with postoperative morbidity and mortality in a group of 100 patients. However, most of the patients in this group had normal albumin levels. The study did suggest, however, that thin male patients were at greater risk for postoperative complications. In this study we found that hypoalbuminemia is a significant predictor of a number of postoperative complications. In addition, a serum albumin level of less than 2.5 g/dL increased the length of hospitalization and mortality. These findings were independent of patient age, sex, BMI, and multiple other potential confounders. A low serum albumin level was a better predictor of mortality in isolated valve and combined valve procedures than in isolated CABG procedures. This study was limited by relying on a single parameter to assess nutritional status. In addition, albumin levels may be affected by chronic congestive heart failure, hepatic insufficiency, renal failure, and systemic illness.¹⁸

Low BMI and low preoperative serum albumin were each independent of one another in their prediction of increased morbidity and mortality after cardiac operations (correlation coefficient $R = 0.07$). The fact that patients with a low BMI and normal albumin level still had an increased mortality suggests that malnutrition causing weight loss or cachexia is not the predominant factor behind their poor outcome. More studies are needed to determine the cause for the inferior outcome in thin patients. Magovern and associates²¹ used both low BMI (<24) and low serum albumin level (<4 g/dL) in their overall risk stratification model for patients undergoing isolated CABG. Even at these levels, low BMI and low albumin level were significant predictors of adverse outcome. Our study suggests that BMI and serum albumin levels should be used to enhance risk stratification models for all patients undergoing cardiac operations.

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Discussion

Dr Lawrence I. Bonchek (*Lancaster, Pa*). We also have evaluated BMI, although not serum albumin, as a risk factor. When we started our study, we thought that high BMI would demonstrate that our obese patients were at higher risk. We found, as you did, that they were not, and that the higher risk was in the low BMI group.

We studied patients with coronary artery disease exclusively. Would you comment on the fact that, by including

patients with valve disease as well as coronary disease, you introduced the variable of heart failure? For instance, albumin could be a surrogate for end-stage heart failure and liver congestion. I would suggest that if you evaluated your subset of patients with coronary disease, you would have a purer study.

In addition, we found that the low BMI marker was particularly striking in older patients, and then even more striking in older women, to the point that for a woman over the age of 70 years who has a BMI of less than 20, with pure coronary disease, our mortality rate in that group is almost 20%. I wonder what your results would be if you divided your data by sex, by age, and by coronary disease alone.

Dr Engelman. Thank you, Dr Bonchek. We did in fact divide our patients by procedure type to evaluate the individual contributions of our 2 risk factors, low BMI and low serum albumin, on patients who had isolated CABG procedures and isolated valve procedures. The effects of low BMI and low albumin level on mortality were independent of the type of surgical procedure. However, whereas the odds ratios of 2.8 and 3 were about the same for low BMI, low preoperative serum albumin level was much more predictive of mortality in patients who had isolated valve procedures than in patients who had isolated CABG procedures. We are not exactly sure of the reason for that. However, BMI seems to have been an indiscriminate indicator of risk.

In answer to your second question, we did divide the patients by sex and age and did not find that sex significantly altered the results, although female patients were at slightly increased risk for mortality after both CABG and valve procedures, and older patients were at still more risk. The combination of female sex and low BMI, however, was not associated with increased risk.

Dr James A. Magovern (*Pittsburgh, Pa*). I want to confirm the findings that you have reported. We published an article a number of years ago on a risk model for predicting morbidity and mortality, and we also found that low serum albumin level and low BMI were independent predictors based on a multivariate regression analysis. We have not been able to determine a plausible mechanism by which a low BMI is associated with increased mortality, but I think it is a clear finding. My own view is that BMI is probably a marker for multiple factors.

In our experience, these patients frequently have a long history of smoking, hypertension, carotid disease, and peripheral vascular disease. I think low BMI is a surrogate for 4 or 5 comarkers. You probably need more data points to ferret that out.

Do you have a mechanism by which low BMI translates into increased risk?

Dr Engelman. We did our best to adjust for all of these increased risk factors. There is no question that patients with a low BMI had increased risk factors. A percentage of these patients had peripheral vascular disease and cerebrovascular disease, although they were less likely to have diabetes. We attempted to adjust in this large group for each of these risk

factors. In taking these out, we do agree, though, that there are other risk factors that we could not account for which may contribute to their increased mortality.

Other possible reasons that a patient with a low BMI would have an increased risk after cardiac surgery, independent of all of these risk factors, are the following: Potentially the patients have smaller targets in CABG, they receive smaller valves, or they have smaller aortas with which to work during combined valve and CABG procedures or iso-

lated valve procedures. They receive potentially more hemodilution on the fixed cardiopulmonary bypass pump during the operation and potentially receive more transfusions to maintain their hemoglobin levels. In addition, a low BMI is probably a marker for nutritional reserve or underlying cachexia in a way that preoperative serum albumin could not assess. For this reason, in our study low serum albumin level was an independent risk factor for mortality and did not seem to depend on low BMI.

Notice of correction

In the May 1998 issue of the Journal, in the article by Liam and associates titled "Hemodilution and Whole Body Oxygen Balance During Normothermic Cardiopulmonary Bypass in Dogs" (J Thorac Cardiovasc Surg 1998;115:1203-8), an error in units of measurement was made. On page 1206, column 2, lines 5 and 7, the unit of measurement should be "kg" rather than "100 gm." The text on line 5 should read " $10 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$." The text on line 7 should read " $(9.8 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1})$."