ORIGINAL SCIENTIFIC ARTICLE

Cardiac Surgery in Nonagenarians and Centenarians

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BACKGROUND: Nonagenarians and centenarians are a rapidly growing segment of the population. No previous study has used a national database to compare outcomes in these patients to those of other groups undergoing cardiac surgical procedures.

STUDY DESIGN: The Society of Thoracic Surgeons National Database was used to review retrospectively 662,033 patients (5 patients more than 100 years of age; 1,092 patients 90 to 99 years; 59,576 patients 80 to 89 years; and 621,360 patients 50 to 79 years of age) who underwent cardiac surgical procedures from 1997 through 2000. These included 575,389 patients who had undergone coronary artery bypass grafting (CABG) only; 56,915 patients with CABG and concomitant mitral or aortic valve replacement or repair (CABG+VALVE); and 49,729 patients with mitral or aortic valve repair or replacement only (VALVE-only). A multivariate logistic regression model was developed to examine predictors of operative mortality in patients more than 90 years of age.

RESULTS: For CABG-only patients, operative mortality was 11.8% for patients more than 90 years of age, 7.1% for those 80 to 89 years, and 2.8% for those 50 to 79 years. The incidence of renal failure and prolonged ventilation was highest among patients more than 90 years of age (9.2% and 12.2%), compared with those 80 to 89 years (7.7% and 10.5%) or 50 to 79 years (3.5% and 6.0%). For VALVE-only patients and CABG+VALVE patients operative mortality for those more than 90 years of age was 11.4% and 12.0%, respectively, compared with 8.3% and 11.5% for those 80 to 89 years and 4.3% and 7.6% for those 50 to 79 years. The major preoperative risk factors for operative mortality among patients more than 90 years of age undergoing isolated CABG were as follows (C-index, 0.68): emergent/salvage: odds ratio, 2.26; 95% confidence interval, 1.38–3.69; preoperative intraaortic balloon pump: odds ratio, 2.79; 95% confidence interval, 1.47–5.32; renal failure: odds ratio, 2.08; 95% confidence interval, 1.12–3.86; peripheral vascular disease or cerebrovascular vascular disease: odds ratio, 1.39, 95% confidence interval, 0.96–2.02; mitral insufficiency: odds ratio, 1.50; 95% confidence interval, 0.93–2.41. Approximately 57% of the nonagenarians and centenarians lacked any of the first four risk factors and had an operative mortality of 7.2%.

CONCLUSIONS: Operative mortality and complication rates associated with cardiac surgical procedures are highest for nonagenarians and centenarians. But with careful patient selection, a majority of these patients have a lower risk of CABG-related mortality approaching that of younger patients. (J Am Coll Surg 2003;197:347–357. © 2003 by the American College of Surgeons)

As recently as two decades ago, performing cardiac surgical procedures on patients aged more than 70 years (ie, septuagenarians) was novel enough to be worthy of reporting.[1,2] In a landmark study published in 1988, Edmunds and colleagues[3] presented the results of 100 consecutive cardiac surgical operations in patients more than 80 years of age. Several other studies also demonstrated that, by using appropriate selection criteria car-

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Abbreviations and Acronyms

AVR = aortic valve replacement
CABG = coronary artery bypass grafting
CONTROL = control group of patients (aged 50 to 79 years)
CVD = cerebrovascular disease
MVR = mitral valve replacement or repair
NONA+ = nonagenarian-and-older patients
OCTA = octagenarian patients
PVD = peripheral vascular disease
STS = The Society of Thoracic Surgeons
VALVE = mitral or aortic valve repair or replacement alone

diac surgical procedures could be performed successfully in octogenarians without prohibitive cost and with acceptable longterm survival and quality of life.[4-13] In the study of Edmunds and colleagues[3] cataloging the prior 11-year experience at the Hospital of the University of Pennsylvania, there was not a single elective cardiac surgical procedure performed on a nonagenarian or centenarian, and we could find only one published series of nonagenarians undergoing cardiac surgical procedures. Samuels and colleagues[14] published a series of 14 patients more than 90 years of age who underwent cardiac surgical procedures at Hahnemann University Hospital in Philadelphia. Six patients had isolated coronary artery bypass grafting (CABG) and eight had isolated aortic valve replacement (AVR). All but one patient survived, but significant morbidity occurred in 71% of patients, primarily as the result of cardiac and neurologic complications. These authors published a followup study in 1999 that included 11 patients who had undergone CABG alone in the same age group, likely representing the eight patients in the original study and three others who had undergone operations in the interim with similar results.[15]

In 1995, patients more than 85 years of age represented only 1.4% of the population, but the United States Census Bureau estimates that this number will increase to 4.6% by the year 2050.[16] Even more striking is the rate of increase in the proportion of centenarians, whose population is projected to increase from 53,000 to nearly 1 million over the same period, representing a growth rate that is more than 10 times as fast as that of the population as a whole.[16] According to the Society of Thoracic Surgeons (STS) National Cardiac Database, cardiac surgical procedures are being performed with increasing frequency in patients more than 90 years of age. In the years 1994 through 2001, the percentage of patients more than 90 years of age more than doubled from 0.7% to 1.6%.[17] Reasons for this increase include a progressive improvement in cardiac surgical risk–adjusted mortality, progress in treating other life-threatening diseases with a resultant increase in life expectancy, and the dramatic age-dependent increase in the frequency of cardiovascular disease. The average rate of first major cardiovascular events increases from 7 in 1,000 for men 35 to 44 years of age to 68 in 1,000 for men 85 to 94 years.[18]

Because no single-institution study is likely to include enough patients to derive a meaningful risk-based assessment, we used an analysis of the STS National Cardiac Database to assist in decision making for physicians and for patients aged more than 90 years and their families contemplating cardiac surgical intervention. The purpose of this analysis was to develop a reasonable risk-based assessment for nonagenarians and centenarians who had undergone coronary artery bypass grafting only (CABG-only), CABG with concomitant mitral or aortic valve replacement or repair (CABG+VALVE), and mitral or aortic valve repair or replacement alone (VALVE-only) from data entered into the STS Database from 1997 through 2000. We addressed the following questions: 1) Do nonagenarians and centenarians have poorer acute outcomes after cardiac surgical procedures compared with octogenarians and other age groups? 2) Are the important preoperative predictors of outcomes similar in this age group to those of other age groups? 3) What is the relative risk profile of nonagenarians and centenarians who undergo cardiac surgical procedures? 4) In this age group, are there important procedure-specific differences in significant risk factors and in outcomes? 5) Can we readily define relatively low-risk and high-risk subsets of patients who are more than 90 years of age?

METHODS

Study population

The study population consisted of 682,033 patients entered into the STS National Cardiac Database between 1997 and 2000 who were more than 50 years of age and had undergone one of the following surgical procedures: CABG-only, CABG with concomitant mitral or aortic valve replacement or repair (CABG+VALVE), or mitral or aortic valve repair or replacement alone (VALVE-only). Patient data were harvested from 47 states in the

United States and 5 provinces in Canada. The final study group had the following age distribution: 5 patients 100 years or more of age; 1,092 patients 90 to 99 years; 59,576 patients 80 to 89 years; and 621,360 patients 50 to 79 years of age. All data elements (risk factors and outcome variables) used in the analysis have been previously defined.[19]

Statistical analyses

Data were analyzed by procedure for the nonagenarian-and-older subset (NONA+) and by age group (CONTROL, age 50 to 79 years; OCTO, age 80 to 89 years). The differences in proportions for categorical variables were assessed using chi-square tests. Mean differences for continuous variables were determined using *t*-tests. Overall unadjusted rates of operative mortality (defined as mortality occurring at any time in the hospital during the same admission or within 30 days of surgical procedures), procedural complications, and length of stay for patients in each age group were also examined for each procedure group. Complications were defined as central neurologic deficit persisting more than 72 hours; pulmonary insufficiency requiring ventilatory support; acute postoperative renal insufficiency; deep sternal infection involving muscle, bone, or mediastinum; and need for reoperation during the same admission.

Unadjusted operative mortality rates for selected subgroups as a function of procedural group were also compared. A logistic regression model of operative mortality was next developed for nonagenarians and centenarians for the CABG-only group using stepwise logistic regression and including all risk factors from the STS CABG risk model as the set of possible predictors. Predictors of mortality were retained in the model if their significance was less than 0.10. From the set of predictors that were significant in the multivariable model a classification tree was used to enable physicians to segregate patients into relatively high-risk and low-risk subsets.[20] The classification tree determines the split among the predictors that maximally distinguishes mortality between the two branches.

RESULTS

General demographics

Of the 1097 NONA+ patients who underwent cardiac surgical procedures there were 663 CABG-only, 193 VALVE-only, and 241 CABG+VALVE cases (Table 1). Among the VALVE-only cases, there were 179 AVRs, 11 mitral valve replacements, and 3 mitral valve repairs (collectively referred to as MVR). Of the CABG+VALVE cases, there were 223 CABG+AVR, 14 CABG and mitral valve replacements, and 4 CABG and mitral valve repairs (collectively referred to as CABG+MVR).

As a function of age group (Table 2), nearly all univariate risk factors differed significantly because of the large number of patients in this analysis ($p < 0.0001$; Table 2). Several differences are worthy of note, however. Patients who underwent CABG only were more likely to smoke and to have hypercholesterolemia, hypertension, diabetes, previous myocardial infarction, or unstable angina than patients who underwent AVR or MVR with or without concomitant CABG. They were also more likely to undergo operation under urgent or emergent circumstances (53.8%) compared with patients in the CABG+VALVE (34.4%) or VALVE-only (26.9%) groups. In contrast, patients who underwent AVR or MVR with or without CABG were more likely to have preoperative arrhythmias and congestive heart failure (Table 1).

For patients who underwent isolated CABG, comparison of demographics for the three age groups was also of interest. We found that the NONA+ patients were significantly more likely to be female (46.7% versus 42.2% and 28.9%, respectively). The mean number of grafts performed was lower for the NONA+ group compared with the CONTROL and OCTO groups (mean $\pm$ SD, 2.9 ± 1.3 versus 3.2 ± 1.3 and 3.3 ± 1.3, respectively). Patients more than 90 years of age who underwent isolated CABG were less likely to have a history of diabetes (16.0% versus 23.8% and 32.9%), smoking (33.2% versus 39.2% and 59.2%), chronic lung disease (8.7% versus 13.9% and 15.0%), or family history of coronary artery disease (21.1% versus 33.0% and 46.5%) than patients in the OCTO and CONTROL groups, respectively, but were more likely to undergo operation under urgent or emergent conditions (53.8% versus 43.2% and 37.0%). They were also more likely to have left main disease (36.7% versus 28.2% and 21.2%), unstable angina (61.4% versus 52.7% and 48.1%), and renal failure (8.1% versus 6.9% and 4.4%), and they were more likely to have congestive heart failure (29.9% versus 21.5% and 13.4%) or to be in New York Heart Association class IV (34.7% versus 28.2% and 22.3%).

The NONA+ group had a higher prevalence of several known powerful preoperative risk factors and a lower prevalence of others compared with younger pa-

Table 1. Nonagenarian and Centenarian Patient Characteristics by Procedure

Characteristic*	CABG-only, n = 663	VALVE-only, n = 193	CABG + VALVE, n = 241
Gender-male	53.7	40.4	48.5
BSA	1.7 ± 0.21	1.7 ± 0.21	1.7 ± 0.21
Smoking history	33.2	26.9	19.5
Family history	21.1	12.4	14.9
Diabetes	16.0	8.8	10.8
Morbid obesity	1.8	1.6	0.8
Hypercholesterolemia	30.8	10.9	21.2
Renal failure	8.1	8.3	7.9
Dialysis	0.6	0.0	1.2
Hypertension	68.9	48.2	64.3
Cerebrovascular accident	7.1	5.7	5.0
Arrhythmia	22.5	38.3	34.9
Chronic lung disease	8.7	10.9	10.4
PVD	17.3	13.5	12.4
Cerebrovascular disease	14.0	11.4	14.1
Prior PTCA	13.9	4.1	5.0
Previous MI	46.9	13.5	20.1
Unstable angina	61.4	5.2	19.1
Congestive heart failure	29.9	65.8	58.1
Cardiogenic shock	5.4	3.6	2.1
Resuscitation	2.3	1.0	0.8
NYHA class			
I	11.6	4.1	5.8
II	9.0	14.0	11.2
III	31.5	41.5	47.3
IV	34.7	24.4	24.5
Previous operations			
1	3.9	6.7	4.1
2+	0.2	0.5	0.4
Status			
Elective	43.9	71.0	63.5
Urgent	45.1	26.9	34.4
Emergent	8.7	0.0	2.1
Salvage	0.9	1.0	0.0
Number of diseased vessels			
1	6.3	3.1	27.4
2	20.1	1.0	29.0
3	67.1	3.1	32.8
Left-main disease	36.7	0.5	16.2
Preoperative IABP	9.4	0.5	0.8
Ejection fraction	49.0 ± 13.4	51.1 ± 13.7	49.8 ± 14.5

*Continuous variables are presented as means ± SD; categorical data are presented as percentage of patients.
BSA, body surface area; CABG, coronary artery bypass; IABP, intraaortic balloon pump; MI, myocardial infarction; NYHA, New York Heart Association; PTCA, percutaneous transluminal angioplasty; PVD, peripheral vascular disease; VALVE, mitral or aortic valve repair or replacement.

tients who underwent isolated CABG. We therefore ascertained whether the patients in the NONA+ group selected to undergo CABG were those with lower overall risk profiles. Using all variables in the STS multivariable CABG risk model except age, we calculated the risk score for each patient across all age groups. The pre-

Table 2. Coronary Artery Bypass Graft–Only Patient Characteristic by Age Group

Characteristic*	Age 50–79, n = 531,308	Age 80–89, n = 43,418	Age ≥ 90, n = 663	p Value
Gender, male	71.1	57.8	53.7	<0.0001
BSA	2.0 ± 0.24	1.8 ± 0.22	1.7 ± 0.21	<0.0001
Smoking history	59.2	39.2	33.2	<0.0001
Family history	46.5	33.0	21.1	<0.0001
Diabetes	32.9	23.8	16.0	<0.0001
Morbid obesity	10.7	3.6	1.8	<0.0001
Hypercholesterolemia	55.0	41.3	30.8	<0.0001
Renal failure	4.4	6.9	8.1	<0.0001
Dialysis	1.1	0.6	0.6	<0.0001
Hypertension	68.6	71.7	68.9	<0.0001
Cerebrovascular accident	6.9	9.5	7.1	<0.0001
Arrhythmia	11.5	20.1	22.5	<0.0001
Chronic lung disease	15.0	13.9	8.7	<0.0001
PVD	15.5	19.6	17.3	<0.0001
Cerebrovascular disease	11.1	17.4	14.0	<0.0001
Prior PTCA	15.8	12.3	13.9	<0.0001
Previous MI	43.1	46.1	46.9	<0.0001
Unstable angina	48.1	52.7	61.4	<0.0001
Congestive heart failure	13.4	21.5	29.9	<0.0001
Cardiogenic shock	2.6	3.6	5.4	<0.0001
Resuscitation	1.0	1.1	2.3	0.0066
NYHA class				<0.0001
I	12.6	10.7	11.6	
II	14.2	12.5	9.0	
III	33.9	33.2	31.5	
IV	22.3	28.2	34.7	
Previous operations				<0.0001
1	7.2	6.5	3.9	
2+	0.7	0.5	0.2	
Status				<0.0001
Elective	61.6	55.2	43.9	
Urgent	31.6	36.7	45.1	
Emergent	5.4	6.52	8.7	
Salvage	0.5	0.6	0.9	
Number of diseased vessels				<0.0001
1	4.4	3.3	6.3	
2	21.4	19.6	20.1	
3	68.0	71.3	67.1	
Left-main disease	21.2	28.2	36.7	<0.0001
Pre-operative IABP	6.4	7.8	9.4	<0.0001
Ejection fraction	50.6 ± 14.0	49.5 ± 14.1	49.0 ± 13.4	<0.0001
Number of grafts				<0.0001
1	7.6	7.8	10.4	
2	14.2	14.1	19.0	
3	31.2	34.0	31.7	
4	43.8	39.9	32.6	
Mean	3.3 ± 1.3	3.2 ± 1.3	2.9 ± 1.3	

Age is given in years.
*Continuous variables are presented as mean ± SD; categorical data are presented as percentage of patients.
BSA, body surface area; IABP, intraaortic balloon pump; MI, myocardial infarction; NYHA, New York Heart Association; PTCA, percutaneous transluminal angioplasty; PVD, peripheral vascular disease.

Table 3. Unadjusted Mortality, Complications, and Length of Stay by Age Group

Characteristic	Age (y)		
Procedure: CABG-only	**50–79**	**80–89**	**≥90+**
n	531,308	43,418	663
Operative mortality (%)	2.8	7.1	11.8
Stroke (%)	1.6	3.2	2.9
Renal failure (%)	3.5	7.7	9.2
Deep sternal wound infection (%)	0.6	0.6	0.3
Prolonged ventilation (%)	6.0	10.5	12.2
Any reoperation (%)	5.1	7.9	8.0
Postoperative LOS (median)	5.0	7.0	7.0
Procedure: VALVE-only			
n	43,407	6,129	193
Operative mortality (%)	4.3	8.3	11.4
Stroke (%)	1.9	3.1	2.1
Renal failure (%)	4.5	7.6	8.3
Deep sternal wound infection (%)	0.5	0.4	0.0
Prolonged ventilation (%)	8.2	13.0	16.1
Any reoperation (%)	8.6	12.0	10.9
Postoperative LOS (median)	6.0	7.0	8.0
Procedure: Combined CABG/ VALVE			
n	46,645	10,029	241
Operative mortality (%)	7.6	11.5	12.0
Stroke (%)	3.3	4.8	5.4
Renal failure (%)	8.4	11.8	10.4
Deep sternal wound infection (%)	0.8	0.6	0.8
Prolonged ventilation (%)	14.7	18.2	18.3
Any reoperation (%)	11.1	13.3	17.8
Postoperative LOS (median)	7.0	8.0	9.0

CABG, coronary artery bypass graft; LOS, length of stay; VALVE, mitral or aortic valve repair or replacement alone.

dicted mortalities were 4.8% for NONA+, 4.1% for OCTA, and 3.1% for CONTROL patients, respectively. When all risk factors other than age were considered the NONA+ group who underwent cardiac surgical procedures represented a higher-risk group of patients than the younger patient groups.

Operative outcomes by procedure and age group

Table 3 lists the acute outcomes of cardiac surgical procedures in each of the three age groups for each of the procedure groups: for CABG-only, the unadjusted mortality was 11.8% for NONA+, 7.1% for OCTO, and 2.8% for patients in the youngest age group. There was a similar age-dependent increase in the frequency of other postoperative complications, including renal failure (defined as creatinine >2.0 and also more than twice the baseline value or a new requirement for dialysis [9.2% versus 7.7% and 3.5%]), prolonged ventilation (defined as postoperative ventilation for more than 24 hours [12.2% versus 10.5% and 6.0%]), and reoperation for any reason (8.0% versus 7.9% and 5.1%). Similar results were obtained in patients who underwent AVR or MVR (VALVE-only; Table 3) and CABG+AVR or CABG+MVR (CABG+VALVE, Table 3). For combined CABG+VALVE patients, the unadjusted mortality was 12.0% for NONA+ versus 11.5% for OCTO and 7.6% for CONTROL patients. Similarly, stroke (5.4% versus 4.8% and 3.3%), prolonged ventilation (18.3% versus 18.2% and 14.7%), and reoperation (17.8% versus 13.3% and 11.1%) were most common in the NONA+ group who underwent isolated valve repair or replacement. For patients who underwent isolated AVR or MVR (VALVE-only), the mortality was also highest for the NONA+ (11.4%) compared with the OCTO (8.3%) and CONTROL groups (4.3%). As observed in patients in the CABG+VALVE group, there were increases in the incidence of postoperative renal failure (8.3% versus 7.6% and 4.5%) and prolonged ventilation (16.1% versus 13.0% and 8.2%), compared with those in the two younger groups of patients, respectively. For all procedure groups, the NONA+ had the longest postopera-

Table 4. Comparison of Operative Mortality for Specific Subpopulations of Nonagenarians and Centenarians by Procedure

	CABG-only mortality rate	VALVE-only mortality rate	CABG/VALVE mortality rate
Gender			
Male	12.1	10.3	12.0
Female	11.5	12.2	12.1
Diabetes			
Yes	15.1	17.7	15.4
No	10.7	11.5	10.9
HTN			
Yes	12.7	11.8	14.2
No	8.9	11.3	9.1
EF > 0.35	11.0	11.5	10.2
EF ≤ 0.35	13.2	13.6	19.1
Renal failure			
Yes	24.1	31.3	21.1
No	10.6	9.6	10.7

CABG, coronary artery bypass graft; EF, ejection fraction; HTN, hypertension; VALVE, mitral or aortic valve repair or replacement alone.

tive length of stay by 2 days on average compared with those in the younger age groups.

Table 4 shows the operative mortality for NONA+ among important clinical subsets in each of the three procedure groups. The operative mortality was remarkably similar in most subsets independent of whether the procedure performed was isolated CABG, AVR or MVR alone, or AVR or MVR combined with CABG. In contrast to several published series examining the impact of gender on CABG operative mortality,[21-25] we did not find female gender to increase mortality risk. For each procedure group, the presence of diabetes, renal failure, or hypertension was associated with a 5% to 57% increase in unadjusted mortality. A moderate reduction in ejection fraction (<35%) was also associated with a marked increase in mortality for combined CABG+VALVE patients (19.1% versus 10.2%) and a smaller increase in mortality for CABG-only patients (13.2% versus 11.0%) and VALVE-only patients (13.6 versus 11.5).

Centenarians

This group consisted of five patients (one woman and four men). All had hypertension and all underwent isolated CABG. Four patients had two diseased vessels and one patient had one diseased vessel. Three had previous myocardial infarctions, and two had previous cardiac surgical procedures. One patient had diabetes, one had peripheral vascular disease (PVD) or cerebrovascular disease (CVD), and another had chronic lung disease. All five patients survived. None of the centenarians had a stroke or a deep sternal wound infection, and none had acute renal failure or need for reoperation. One centenarian required prolonged ventilation.

Risk Model Comparisons

We used stepwise logistic regression analysis to identify preoperative characteristics that were associated with operative mortality. The only group large enough to obtain meaningful results was the CABG-only group (Table 5). The risk factors listed in Table 5 are arranged according to their contribution to the predictive power of the overall model (as assessed by the value of the Wald chi-square statistic). The need for emergent or salvage surgical procedures, presence of a preoperative intraaortic balloon pump (IABP), renal failure, PVD or CVD, and presence of mitral insufficiency emerge as the most compelling multivariate predictors of operative mortality. The overall ability of this model to discriminate patients who would live from those who would die was acceptable (area under the receiver operating characteristic curve or C-statistic, 0.68). The risk factors predictive of mortality were nearly identical for each of the three age groups.

Table 5. Multivariable Logistic Regression Model for Operative Mortality as the Outcome for Nonagenarians and Centenarians, Coronary Artery Bypass Graft–Only

	Odds ratio	95% CI	Wald chi-square
Emergent/salvage	2.26	1.38–3.69	10.47
IABP (preoperative)	2.79	1.47–5.31	9.81
Renal failure/dialysis	2.08	1.12–3.86	5.32
PVD/CVD	1.39	0.96–2.02	2.96
Mitral insufficiency	1.50	0.93–2.41	2.80
C-index	0.68		

CI, confidence interval; CVD, cerebrovascular disease; IABP, intraaortic balloon pump; PVD, peripheral vascular disease.

We used the five risk factors derived from the multivariate analysis to construct a classification tree. The algorithm employed selects the variable that maximally discriminates between high and low mortality subsets at each branch point. We pared down the tree to avoid an unwieldy number of groups with insignificant sample sizes. We also sought to identify a relatively low-risk group that represented a sizable percentage of the patients. The results of this analysis are presented in Figure 1. For NONA+ undergoing isolated CABG, those patients in whom procedures were performed under emergent or salvage circumstances had a mortality of 26.6%. Those with procedures performed less emergently but with a preoperative IABP had a similar mortality of 26.3%. Patients without either of these risk factors had a 20.9% mortality if they had renal failure. Patients with PVD or CVD (without renal failure, preoperative IABP, or emergent or salvage surgical procedures) had a mortality of 10.6%. Finally, patients without any of these risk factors accounted for 57% of the NONA+ group who underwent isolated CABG and had mortality of 7.2%.

Finally, we formally examined the interactions between risk factors and found that for NONA+ who underwent isolated CABG only the interaction between emergent or salvage status and PVD or CVD was significant. Specifically, in patients whose surgical procedures were elective or urgent (not emergent or salvage), the presence of PVD or CVD only increased mortality from 10% to 11%. In patients whose procedures were emergent or salvage, the presence of PVD or CVD increased

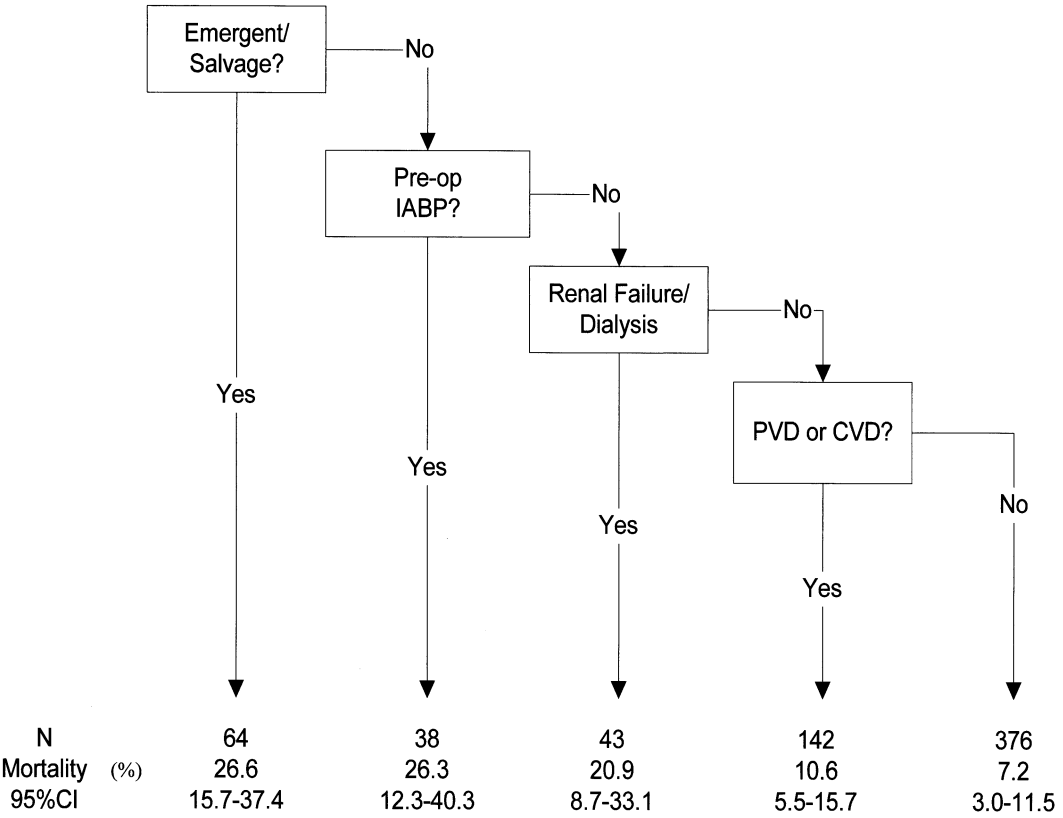

Figure 1. Classification tree: coronary artery bypass grafting-only operative mortality for subsets of nonagenarians and centenarians. CVD, cerebrovascular disease; IABP, intraaortic balloon pump; PVD, peripheral vascular disease.

mortality from 18% to 33%. The five NONA+ patients with emergent or salvage surgical procedures in the presence of both PVD and CVD had a mortality of 80%.

DISCUSSION

This study is the first use of a national database to investigate the risks of cardiac surgical procedures in patients more than 90 years of age with a multiinstitutional patient population nearly twice as large as any previously reported. Our findings support the hypothesis that nonagenarians and centenarians who undergo cardiac surgical procedures represent a higher-risk group of patients independent of age. But this study also demonstrates that a majority of these nonagenarians and centenarians can be preoperatively identified to have a relatively low risk of mortality. Accordingly, our results should be used as a basis to consider more rationally the possibility of elective cardiac surgical procedures in these patients.

Demographic characteristics

Overall, patients more than 90 years of age who underwent cardiac surgical procedures had a lower prevalence of certain known risk factors for cardiac surgical treatment. They had less diabetes, were less likely to smoke, were less often obese, and had a lower incidence of both hypercholesterolemia and chronic lung disease. Many of these risk factors for cardiac surgical procedures are also associated with a decrease in life expectancy. Perhaps the reason that these factors are relatively rare in nonagenarians and centenarians who undergo cardiac surgical procedures is that only in the absence of these risk factors is an individual likely to live long enough to become a nonagenarian. Interestingly, there was no gender difference in the NONA+ group, reflecting the longer life expectancy for women; at ages greater than 90 years, women outnumber men by 2:1.[14,26]

Mortality characteristics

This study demonstrates that cardiac surgical procedures can be performed safely with acceptable risk in a prop-

erly selected segment of the extremely elderly population. Regardless of the procedure (including CABG, MVR, AVR, or combined procedures), the overall survival of the nonagenarians and centenarians who underwent cardiac surgical procedures approached 90%. With the results of this study, more than 50% of the nonagenarians and centenarians who underwent isolated CABG could have been preoperatively identified as being at low risk; this subgroup had a survival of 92.8%.

At the other end of the spectrum, those subsets with significantly increased unadjusted mortality included patients with diabetes, preoperative renal failure or hypertension, and moderate ventricular dysfunction (Table 4). In evaluating NONA+ patients preoperatively, it is critical to assess accurately these preoperative characteristics, not only for mortality but also for the likelihood of postoperative complications and prolonged morbidity. Interestingly, in contrast to results in younger patients,[21-25] there was no difference in mortality based on gender in this NONA+ analysis. For all major complications after CABG, the unadjusted complication rates increased with age except for stroke and deep sternal wound infection. Variations in this trend in the VALVE and CABG+VALVE NONA+ groups were probably caused by small sample sizes for these subcategories (Table 3).

Risk-Adjusted Analyses

Table 5 and Figure 1 outline an algorithm for selection of NONA+ patients for CABG-only intervention. At a mortality rate of 26.6%, it can be argued that performing emergent or salvage CABG on NONA+ patients is inappropriate, depending on the clinical circumstances. Conversely, NONA+ patients without the preoperative characteristics of emergent or salvage status, preoperative IABP for pain or hemodynamic support, renal failure with or without dialysis, or significant PVD or CVD are very reasonable candidates for CABG under the right clinical indications and should not be denied the option of surgical procedures under the right circumstances. This study not only quantifies the risk of cardiac surgical intervention in this fastest growing segment of our population, but also provides an evidence-based algorithm for reasonable preoperative selection of patients and evaluation of surgical risk.

Because of the age of these patients, increasingly scarce health care resources, and the ethical factors that affect decision making regarding any surgical intervention in nonagenerian population, information such as presented here is critically helpful not only to providers, but also to these patients and their families. These data should be helpful in a rational risk–benefit analysis to assess the relative merits of therapeutic alternatives in nonagenerian patients with surgical cardiovascular disease. Patients more than 80 years of age have a greater absolute risk reduction associated with CABG or percutaneous transluminal coronary angioplasty than do younger patients.[27] In addition, the complications of percutaneous transluminal coronary angioplasty increase disproportionately in patients beyond the eighth decade of life,[28] and the coronary anatomy is often more suitable for bypass than for percutaneous transluminal coronary angioplasty.[29] Among patients selected appropriately based on preoperative factors and clinical status, CABG might be the treatment of choice for some of these nonagenerian patients and the same might be true for selected patients with aortic and mitral disease.

The end of life is a highly personal issue in which religion and philosophy necessarily and appropriately dominate our thought processes as patients, family members, and health care providers. In the coming decades, nonagenarians and centenarians will be viewed as a rapidly growing minority group of productive citizens. Using data from evidence-based medicine, in this age subset with cardiovascular disease all therapeutic options should be considered, including cardiac surgical procedures. Ideally, a treatment plan instituted should be based on a careful assessment of the patient's and family's wishes, the relative medical risks and benefits, and the economic costs of the alternatives.

Author Contributions

Study conception and design: Bridges, Edwards, Ferguson
Acquisition of data: Bridges
Analysis and interpretation of data: Coombs
Drafting of manuscript: Bridges, Edwards, Peterson
Critical revision: Bridges, Edwards, Peterson, Ferguson
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Invited Commentary

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I would like to thank the authors for an authoritative presentation and for an opportunity to review their manuscript.

Reviewing our results from 1996 to 2001 confirms these findings. We performed 6,636 procedures in patients less than 80 years of age, 353 in octogenarians, and 9 in patients more than 90 years old. The mean age of these patients was 96.7, and two were more than 100 years old. We saw a similarly low incidence of most preoperative risk factors, had remarkably low postoperative complication rates, and no mortality. We also saw a 100% incidence of unstable angina, indicating a compelling need for intervention.

We used the New York State algorithm to predict operative mortality. Our experience indicates an increasing ability to out-perform this algorithm, confirming improving surgical ability in all age groups and particularly in the group discussed today.

The number of potential patients in each age group declines gradually after age 50. The distribution of CABG patients is skewed to the right, consistent with the relationship of coronary artery disease to increasing