Contemporary outcomes of open thoracoabdominal aortic aneurysm repair in octogenarians

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Objectives: We sought to evaluate our contemporary outcomes with open thoracoabdominal aortic aneurysm (TAAA) repair in octogenarians to determine whether open TAAA repair is a viable option, with acceptable risk, in this elderly cohort.

Methods: We analyzed clinical data from 1267 enrolled patients who underwent open TAAA repair between 2003 and 2013. Eighty-eight patients (7%) were octogenarians (median age, 82 years; range, 80-92 years) and 1179 were 79 years of age or less.

Results: Aneurysm rupture was more common in octogenarians (14% vs 4.7%, $P = .001$), whereas aortic dissections predominated in younger patients (43.9% vs 13%, $P < .001$). Octogenarians had higher rates of visceral-branch endarterectomy/stenting (58% vs 33.5%, $P < .001$), adverse postoperative outcomes (36% vs 15.3%, $P < .001$), operative mortality (26% vs 6.9%, $P < .001$), and prolonged hospital stay ($P = .004$). Among octogenarians, preoperative aortic dissection was most commonly associated with extent I repair (42% vs <10% for other extents, $P < .001$). Extent II repairs most frequently necessitated concomitant visceral-branch procedures and carried the highest risk of mortality (62%). Extent I and III repairs carried intermediate operative risk, and extent IV repairs posed the least risk (11%). Multivariate modeling analysis identified extent II TAAA ($P = .001$; odds ratio, 11.6), presence of concomitant dissection ($P = .02$; odds ratio, 5.6), and aneurysm rupture ($P = .02$; odds ratio, 5.7) as independent predictors of operative mortality in octogenarians.

Conclusions: Open extent II TAAA repair carries significant risk for octogenarians; extent I, III, and IV repairs incur more reasonable postoperative risk. Although TAAA repair should not be denied to octogenarians based solely on age, extensive TAAA repair should be performed with caution. (*J Thorac Cardiovasc Surg* 2015;149:S134-41)

See related commentary on pages S142-3.

Nonsurgical treatment of thoracoabdominal aortic aneurysms (TAAAs) carries a poor prognosis.¹ The mainstay in managing TAAAs has been open surgical repair^{2,3}; however, historically this is associated with a substantial risk of perioperative mortality and morbidity.^{3,4} The use of improved contemporary techniques⁵⁻⁸ for end-organ

protection has resulted in greatly improved outcomes.⁹⁻¹² Although most patients undergo TAAA repair in their 60s,^{2,3,9-12} many older patients remain at risk for TAAA. Worldwide, people 80 years of age and older are the fastest growing segment of the population.¹³ Currently, there are 11.9 million octogenarians in the United States, which constitutes the world's second largest octogenarian population, and this number is projected to nearly triple by 2050.¹³ On reaching the age of 80 years, life expectancy for Americans is 8.9 years,¹⁴ and thus, measures to extend life are often warranted.

Multiple series have reported that major cardiovascular surgery can be performed with acceptable perioperative mortality and excellent postoperative quality of life in appropriately selected octogenarians.¹⁵⁻¹⁹ Conversely, other reports and national registries have shown that cardiovascular surgery in older patients overall incurs higher mortality, major complication rates, and total cost than in younger populations.²⁰⁻²² The purpose of this study is to report our contemporary experience with open TAAA repair in octogenarians and compare it with the outcomes in a younger population to determine whether open TAAA repair is a viable option in this high-risk cohort.

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Abbreviations and Acronyms

CSF	= cerebrospinal fluid
IQR	= interquartile range
LHB	= left heart bypass
OR	= odds ratio
TAAA	= thoracoabdominal aortic aneurysm

PATIENTS AND METHODS

The Baylor College of Medicine institutional review board approved our clinical research protocol in 2006. For patients who underwent surgery after protocol approval, clinical data were collected prospectively and informed consent was obtained whenever possible; waiver of consent was approved for patients who were unable to provide consent as a result of their illness if they did not have family members available. For patients who underwent surgery before protocol approval, data were collected retrospectively and consent was waived with approval.

From January 2003 to September 2013, 1279 consecutive patients underwent open TAAA repair; 12 (0.9%) patients did not provide consent and did not meet the criteria for waiver. Of the 1267 patients enrolled, 88 (7%) were octogenarians and 1179 (93.1%) were 79 years old or less; these groups are the focus of this study. Operative mortality²³ (early death) was defined as death occurring within 30 days of surgery or before final discharge from hospital (including any time hospitalized in cases of transfer). Adverse event, a composite end point, was defined as the occurrence of any of the following: operative death, stroke, or permanent (defined as present at time of hospital discharge) paraplegia, paraparesis, or renal failure requiring dialysis.²⁴ All the preoperative, operative, and outcomes variables were collected using standard definitions as reported in recent publications.^{11,25}

Surgical Technique

Our current technique of TAAA repair has been described in recent publications.^{25,26} We used moderate heparinization and mild permissive hypothermia in all repairs on octogenarians. For extent I and II TAAA repairs, we routinely used cerebrospinal fluid (CSF) drainage and left heart bypass (LHB) to provide distal aortic perfusion during aortic crossclamping; these adjuncts were used selectively in other extents. When appropriate, we also used sequential crossclamping techniques and selectively reimplanted intercostal and lumbar arteries. We selectively perfused the celiac and superior mesenteric arteries with isothermic blood from the LHB circuit, and, whenever accessible, delivered intermittent cold (4°C) perfusion to the renal arteries. We assessed the origins of renal and visceral arteries for occlusive disease or dissection. In case of significant stenosis caused by atherosclerosis or dissection, endarterectomy, balloon-expandable stent deployment, or both were used to enhance renal and visceral perfusion.²⁷

Follow-up

Follow-up was completed for all surviving octogenarian patients and 92% of surviving nonoctogenarians; median follow-up was 35.4 months (interquartile range [IQR], 15.7-68.8 months) and 39.2 months (IQR, 9.7-69.7 months), respectively. Clinical and research staff telephoned the patients, their designated family members, and physicians. When telephone contact was not successful, letters were mailed to the patients' last mailing address. The Social Security Death Index was queried to determine the patients' vital status.

Statistical Analysis

The data are summarized as n (%) for all discrete variables. Continuous data are presented as either median and interquartile range, or

mean $\pm$ standard deviation. Associations between TAAA extent and preoperative characteristics, surgical details, outcomes, and causes of early death were calculated among the 88 octogenarians and compared with those of nonoctogenarians. Binary variables were analyzed using the Pearson χ^2 or Fisher exact test when expected cell sizes were small. Continuous variables with nonnormal distribution and nonequal variances were analyzed using the Kruskal-Wallis equality of populations rank test. Further analyses focused on associations between demographics, preoperative characteristics, operative variables, and outcomes among octogenarians and nonoctogenarians for all TAAA extents. We sought to identify significant predictors of operative mortality and adverse events among octogenarians using logistic regression modeling techniques. Bivariate associations with *P* values less than .25 were considered for entry into the models. A forward stepwise selection algorithm with a likelihood ratio criterion was used to build the regression models, which were stratified by age group. Analyses were performed using Stata IC 13 (Stata Statistical Software release 13. StataCorp, College Station, Tex) and IBM SPSS Statistics 21 (released 2012. IBM SPSS Statistics for Windows, version 21.0. IBM Corp, Armonk, NY). Survival was determined with the Kaplan-Meier method of estimation and the intergroup comparison was performed using the log-rank test.

RESULTS

During an 8-year period, 88 octogenarians (median age, 82 years [81-83.5]; range, 80-92 years) underwent open TAAA repair. Significant differences existed between octogenarians and nonoctogenarians with regard to baseline characteristics, comorbidities, and distribution of extent of repair (Table 1). Octogenarians had a higher incidence of aneurysm rupture (14%) and acute symptoms (25%) at presentation than nonoctogenarians (4.7%, *P* = .001, and 15.0%, *P* = .03, respectively). Conversely, nonoctogenarians had more aortic dissections (43.9%) than octogenarians (13%, *P* < .001).

Although most of the baseline characteristics for octogenarians did not differ significantly by extent of repair, the distribution of aortic dissection, the presence of acute symptoms, and coronary artery disease did vary significantly (Table 2). These patients had more extent I TAAA aortic repairs for dissection (42%, *P* < .001) and more extent III TAAA repairs for acute symptoms (43%, *P* = .03) than other extents. Aneurysm rupture was present in 25% of octogenarians undergoing extent III repairs. More than half of the extent III repairs (54%) were performed either urgently or as an emergency (Table 3).

As expected, the use of operative techniques in octogenarians varied by extent of repair (Table 3). LHB was used in most extent I (79%) and extent II repairs (85%). Similarly, CSF drainage was used mostly in extent I (95%) and extent II repairs (100%). Cold renal perfusion was used in most extent II (85%), III (86%), and IV (93%) repairs. Selective visceral perfusion to the celiac and superior mesenteric arteries was provided in most extent II repairs (62%, *P* < .001). Extent II TAAA repairs required more branch vessel adjuncts, such as concurrent endarterectomy or stenting or both, compared with other extents (85%, *P* < .001). Overall, octogenarians required significantly more renal/visceral vessel endarterectomy or

TABLE 1. Preoperative clinical and select operative characteristics of 88 octogenarian patients who underwent open thoracoabdominal aortic aneurysm repair compared with patients less than 80 years old

Variables	All (n = 1267), n (%)	<80 Years (n = 1179), n (%)	≥80 Years (n = 88), n (%)	P value
Age, y, median [IQR]	66 [57-73]	65 [56-71]	82 [81-84]	<.001
Male	828 (65.3)	775 (65.7)	53 (60)	.3
Aortic dissection	528 (41.7)	517 (43.9)	11 (13)	<.001
Acute or subacute	48 (3.8)	46 (3.9)	2 (2)	<.001
Chronic	480 (37.9)	471 (39.9)	9 (10)	
Diabetes	130 (10.3)	115 (9.7)	15 (17)	.1
Hypertension	1111 (87.7)	1032 (87.5)	79 (90)	.8
Coronary artery disease	430 (33.9)	395 (33.5)	35 (40)	.2
Cerebrovascular disease	185 (14.6)	164 (13.9)	21 (24)	.01
Chronic renal insufficiency*	37 (2.9)	35 (3.0)	3 (3)	1.0
Pulmonary disease	566 (44.7)	533 (45.2)	33 (38)	.3
Symptomatic at time of repair	892 (70.4)	824 (69.9)	68 (77)	.1
Acute symptoms†	199 (15.7)	177 (15.0)	22 (25)	.01
Chronic symptoms	694 (54.8)	647 (54.9)	47 (53)	
Rupture at time of repair	67 (5.3)	55 (4.7)	12 (14)	.001
Extent of TAAA repair				
I	319 (25.2)	300 (25.4)	19 (22)	<.001
II	398 (31.4)	385 (32.6)	13 (15)	
III	261 (20.6)	233 (19.8)	28 (32)	
IV	289 (22.8)	261 (22.1)	28 (32)	

IQR, Interquartile range; TAAA, thoracoabdominal aortic aneurysm. *Chronic renal insufficiency is defined as a serum creatinine level of at least 3.0 mg/dL. †Priority is given to acute symptoms. Patients with both acute and chronic symptoms are presented here as having acute symptoms.

stenting or both (58%) than nonoctogenarians (33.6%, $P < .001$).

There were 23 early deaths (26%) in the octogenarian group. There were no intraoperative deaths. The predominant causes of death were respiratory failure

(n = 5) and primary multisystem organ failure (n = 5). Other primary causes of death included gastrointestinal complications (n = 4, including 1 case of pancreatitis), cardiac failure (n = 2), stroke (n = 1), acute renal failure (n = 1), bleeding (n = 1), aspiration (n = 1), sepsis

TABLE 2. Preoperative clinical characteristics of 88 octogenarian patients who underwent open thoracoabdominal aortic aneurysm repair, stratified by extent of repair

Variables	All (n = 88), n (%)	Extent I (n = 19), n (%)	Extent II (n = 13), n (%)	Extent III (n = 28), n (%)	Extent IV (n = 28), n (%)	P value
Age, y, median [IQR]	82 [81-84]	82 [80-85]	81 [80-82]	82 [81-84]	83 [81-84]	.4
Male	53 (60)	11 (58)	7 (54)	14 (50)	21 (75)	.2
Aortic dissection	11 (13)	8 (42)	1 (8)	1 (4)	1 (4)	<.001
Acute or subacute	2 (2)	2 (11)	0	0	0	.002
Chronic	9 (10)	6 (32)	1 (8)	1 (4)	1 (4)	
Diabetes	15 (17)	4 (21)	4 (31)	5 (18)	2 (7)	.2
Hypertension	79 (90)	16 (84)	13 (100)	25 (89)	25 (89)	.6
Coronary artery disease	35 (40)	3 (16)	3 (23)	13 (46)	16 (57)	.02
Cerebrovascular disease	21 (24)	3 (16)	5 (39)	7 (25)	6 (21)	.5
Chronic renal insufficiency*	3 (2)	0	1 (8)	2 (7)	0	.5
Pulmonary disease	33 (38)	4 (21)	7 (54)	14 (50)	8 (29)	.1
Smoking history						
Never smoked	21 (24)	7 (37)	2 (15)	4 (14)	8 (29)	.5
Current smoker	12 (14)	1 (5)	3 (23)	4 (14)	4 (14)	
Former smoker	53 (60)	11 (58)	8 (62)	18 (64)	16 (57)	
Unknown history	2 (2)	0	0	2 (7)	0	
Symptomatic at time of repair	68 (77)	15 (79)	9 (69)	23 (82)	21 (75)	.1
Acute symptoms†	22 (25)	1 (5)	2 (15)	12 (43)	7 (25)	.03
Chronic symptoms	46 (52)	14 (74)	7 (54)	11 (39)	14 (50)	.1
Rupture at time of repair	12 (14)	2 (11)	0	7 (25)	3 (11)	.2

IQR, Interquartile range. *Chronic renal insufficiency is defined as a serum creatinine level of at least 3.0 mg/dL. †Priority is given to acute symptoms. Patients with both acute and chronic symptoms are presented here as having acute symptoms. There were 2 patients with acute symptoms in addition to chronic symptoms.

TABLE 3. Surgical details of 88 octogenarian patients who underwent open thoracoabdominal aortic aneurysm repair, stratified by extent of repair

Variables	All (n = 88), n (%)	Extent I (n = 19), n (%)	Extent II (n = 13), n (%)	Extent III (n = 28), n (%)	Extent IV (n = 28), n (%)	P value
Urgency of surgical repair						
Elective	60 (68)	17 (90)	11 (85)	13 (46)	19 (68)	.009
Emergency or urgent	28 (32)	2 (11)	2 (15)	15 (54)	9 (32)	
Previous aortic operation	33 (38)	5 (26)	6 (46)	12 (43)	10 (36)	.6
Adjuncts to aortic repair						
Left heart bypass	27 (31)	15 (79)	11 (85)	1 (4)	0	<.001
Cerebrospinal fluid drainage	53 (60)	18 (95)	13 (100)	14 (50)	8 (29)	<.001
Intercostal/lumbar reattachment	22 (25)	12 (63)	8 (62)	2 (7)	0	<.001
Cold renal perfusion	63 (72)	2 (11)	11 (85)	24 (86)	26 (93)	<.001
Isothermic visceral perfusion	14 (16)	4 (21)	8 (62)	1 (4)	1 (4)	<.001
Use of bypass graft						
Celiac	5 (6)	2 (11)	0	1 (4)	2 (7)	.8
SMA	4 (5)	0	0	2 (7)	2 (7)	.7
Right renal	12 (14)	0	3 (23)	4 (14)	5 (18)	.2
Left renal	32 (36)	0	9 (69)	12 (43)	11 (39)	<.001
Four branch graft	5 (8)	0	0	3 (11)	2 (7)	.5
Endarterectomy						
Right or left renal	43 (49)	1 (5)	10 (77)	15 (54)	17 (61)	<.001
Celiac	20 (23)	1 (5)	6 (46)	9 (32)	4 (14)	.02
SMA	22 (25)	1 (5)	6 (46)	10 (36)	5 (18)	.02
Any visceral vessel	45 (51)	1 (5)	10 (77)	17 (61)	17 (61)	<.001
Stent placement						
Right or left renal	25 (28)	1 (5)	4 (31)	8 (29)	12 (43)	.03
Celiac	4 (5)	0	1 (8)	3 (11)	0	.2
SMA	6 (7)	1 (5)	2 (15)	1 (4)	2 (7)	.6
Any visceral vessel	29 (33)	2 (11)	6 (46)	9 (32)	12 (43)	.07
Endarterectomy or stent placement or both	51 (58)	2 (11)	11 (85)	19 (68)	19 (68)	<.001

SMA, Superior mesenteric artery.

(n = 1), and aortic aneurysm rupture (n = 1). In several patients, primary events progressed to sepsis (n = 5) or secondary multiorgan failure (n = 7) or both (n = 1). One patient died at home of unknown cause. Octogenarians who underwent extent II TAAA repair had the highest risk of operative mortality (62%, $P = .007$), in-hospital death (62%, $P = .008$), and adverse events (77%, $P = .006$) compared with other extents (Table 4). Postoperative renal failure that required dialysis at discharge occurred in 20 (23%) octogenarians and was significantly higher after extent II repairs than after other extents (69%, $P < .001$).

Compared with younger patients, octogenarians had a significantly increased risk of adverse events ($P < .001$), operative mortality ($P < .001$), in-hospital death ($P < .001$), 30-day death ($P = .002$), and other complications (Table 5). Postoperative renal failure that required permanent dialysis was also significantly higher in octogenarians ($P < .001$). Permanent spinal cord deficits tended to occur more frequently in octogenarians than in nonoctogenarians ($P = .08$). Octogenarians experienced a

longer hospital stay ($P = .004$) than nonoctogenarians (Table 5). Survival was significantly lower in octogenarians than nonoctogenarians: $64.5\% \pm 5.1\%$ versus $88.4\% \pm 1.0\%$ at 6 months, and $63.3\% \pm 5.2\%$ versus $84.4\% \pm 1.1\%$ at 1 year, respectively ($P < .001$) (Figure 1).

Multivariate modeling analysis identified extent II TAAA ($P = .001$; odds ratio [OR], 11.6), concomitant dissection ($P = .02$; OR, 5.6), and aneurysm rupture ($P = .02$; OR, 5.7) as independent predictors of operative mortality in octogenarians. Extent II TAAA ($P = .002$; OR, 9.5) and concomitant dissection ($P = .03$; OR, 4.7) were also identified as predictive for adverse event in octogenarians (Table 6).

COMMENTS

Because of the existing aging population, it has become increasingly common to perform major cardiovascular procedures on patients older than 80 years of age. These patients typically have substantial preexisting comorbid conditions. We sought to evaluate our contemporary outcomes with open TAAA repair in octogenarians to

TABLE 4. Early outcomes for 88 octogenarian patients who underwent open thoracoabdominal aortic aneurysm repair, stratified by extent of repair

Variables	All (n = 88), n (%)	Extent I (n = 19), n (%)	Extent II (n = 13), n (%)	Extent III (n = 28), n (%)	Extent IV (n = 28), n (%)	P value
Operative mortality	23 (26)	6 (32)	8 (62)	6 (21)	3 (11)	.007
In-hospital death	22 (25)	5 (26)	8 (62)	6 (21)	3 (11)	.008
Death within 30 d	12 (14)	2 (11)	5 (39)	3 (11)	2 (7)	.07
Adverse event*	32 (36)	8 (42)	10 (77)	8 (29)	6 (21)	.006
Permanent spinal cord deficit	9 (10)	3 (16)	3 (23)	2 (7)	1 (4)	.2
Permanent paraplegia	7 (8)	2 (11)	3 (23)	2 (7)	0	.05
Acute renal dysfunction	21 (24)	3 (16)	9 (69)	4 (14)	5 (18)	.002
Renal failure requiring dialysis at discharge	20 (23)	3 (16)	9 (69)	4 (14)	4 (14)	.001
Stroke	5 (6)	1 (5)	3 (23)	0	1 (4)	.03
Cardiac complication	38 (43)	9 (47)	5 (39)	13 (46)	11 (39)	.9
Pulmonary complication	46 (52)	11 (58)	10 (77)	14 (50)	11 (39)	.1
Vocal cord paralysis	5 (6)	3 (16)	1 (8)	0	1 (4)	.08
Bleeding requiring reoperation	6 (7)	2 (11)	0	1 (4)	3 (11)	.6
ICU length of stay, d; median [IQR]†	5 [3-10]	6.5 [3-13]	5 [4-12]	4 [3-7]	4 [3-6]	.6
Hospital length of stay, d; median [IQR]†	14 [9-38]	13 [11-22]	24 [21-44]	14 [9-19]	11 [9-42]	.4
Transfer to LTAC for additional care	31 (48)	8 (42)	6 (46)	8 (29)	9 (32)	.5

IQR, Interquartile range; ICU, intensive care unit; LTAC, long-term acute care facility. *Adverse event is a composite end point that was defined as the occurrence of any of the events including operative death, stroke, permanent (at discharge) renal failure, paraplegia, or paraparesis. †Data for early survivors (n = 65) only.

determine whether open TAAA repair is a viable option with an acceptable risk level in this elderly cohort.

Sagban and colleagues¹⁷ reported a 30-day mortality rate of 24% in 17 octogenarians after open TAAA repair. Similarly, Huynh and colleagues¹⁸ reported a 25% 30-day mortality rate associated with thoracoabdominal and descending thoracic aortic aneurysm surgery in 56 patients aged 79 years or older; to get an estimate of the risk in a smaller sample size, the authors combined the variables of emergency presentation, congestive heart failure, or diabetes into a high-risk category. The 30-day mortality rate was 50% for high-risk patients and 17% for low-risk patients ($P < .03$). Nearly 2 decades ago, we reported our experience in 39 consecutive open TAAA repairs in octogenarians.¹⁵ Although 7 patients (18%)

presented with aortic rupture, all patients were considered relatively healthy and hemodynamically stable, and we surmised that this was a lower-than-typical risk cohort, and that perhaps the sickest patients did not survive the transfer process to our tertiary care center. In the former series, in-hospital mortality was 10%, the incidence of paraplegia or paraparesis was 5%, and renal failure requiring dialysis occurred in 8%. We believe that, unlike our former series, our current series of octogenarians represents a substantially higher risk cohort, which may explain our much greater rate of mortality (26%) and renal failure (23%). In addition, the increased complication rates in our current series may be a byproduct of our enhanced approach to standardized prospective data collection, or possibly may reflect the ability of a contemporary patient

TABLE 5. Early outcomes for 88 octogenarian patients who underwent open thoracoabdominal aortic aneurysm repair compared with patients less than 80 years old

Variables	All (n = 1267), n (%)	<80 (n = 1179), n (%)	≥80 (n = 88), n (%)	P value
Operative mortality	104 (8.2)	81 (6.9)	23 (26)	<.001
In-hospital death	97 (7.7)	75 (6.4)	22 (25)	<.001
Death within 30 d	69 (5.4)	57 (4.8)	12 (14)	.002
Adverse event*	212 (16.7)	180 (15.3)	32 (36)	<.001
Permanent spinal cord deficit	75 (5.9)	66 (5.6)	9 (10)	.08
Renal failure requiring dialysis at discharge	84 (6.6)	64 (5.4)	20 (23)	<.001
Stroke	43 (3.4)	38 (3.2)	5 (6)	.2
Cardiac complication	356 (28.1)	318 (27.0)	38 (43)	.001
Pulmonary complication	478 (37.7)	432 (36.6)	46 (52)	.004
Vocal cord paralysis	236 (18.6)	231 (19.6)	5 (6)	.001
ICU length of stay, d; median [IQR]†	4 [3-7]	4 [3-7]	5 [3-10]	.2
Postoperative length of stay, d; median [IQR]†	11 [8-17]	11 [8-16]	14 [9-38]	.004

IQR, Interquartile range; ICU, intensive care unit. *Adverse event is a composite end point that was defined as the occurrence of any of the events including operative death, stroke, and permanent (at discharge) renal failure, paraplegia, or paraparesis. †Data for early survivors (n = 65) only.

FIGURE 1. Kaplan-Meier survival analysis of 1267 open thoracoabdominal aortic aneurysm repairs stratified by age <80 or ≥80 years for the first year after repair.

referral system to better deliver acutely ill patients to tertiary treatment centers.

Our current series showed a high prevalence of comorbid conditions, such as hypertension, coronary artery disease, diabetes, and cerebrovascular disease, in octogenarians (Tables 1 and 2). In addition, we found that most octogenarians presented for repair when symptomatic (77%) and that many (25%) were acutely symptomatic. In addition, 32% of these patients underwent an emergency or urgent repair; in the case of extent III TAAA repair, this increased to 54%. Similar to previous studies,^{15,28,29} this study showed that octogenarians had a substantially higher rate of rupture (14%) than nonoctogenarians (4.7%, $P < .001$). Aortic rupture at the time of repair was present in 12 octogenarians; more than half of these patients ($n = 7$) received extent III TAAA repairs and almost half (42%) did not survive. Although the incidence of chronic renal insufficiency was similar in octogenarians and nonoctogenarians, it is notable that all 3 octogenarian patients with preoperative renal

insufficiency died after repair. Although aortic dissection was relatively uncommon in octogenarians, the 2 patients who presented with acute aortic dissection did not survive repair, and modeling demonstrated that aortic dissection (acute or chronic) was predictive of both operative mortality and adverse events. Many of our octogenarian patients had known aortic disease and 38% of them had undergone previous aortic repair; in the case of extent II TAAA repair, this increased to 46%.

Additional comorbid considerations in octogenarians include a substantial atherosclerotic burden and related occlusive disease. In contrast to nonoctogenarians, octogenarians (especially those undergoing extents III or IV repair), presented with a disease process that was less frequently related to chronic aortic dissection or the presence of connective tissue disorders. We surmise that TAAA in octogenarians is more often an age-related process associated with atherosclerosis. In Crawford's lifetime experience of 1509 TAAA repairs,³ 18.0% of patients undergoing such repair (median age, 67 years) had concomitant visceral and renal artery occlusive disease. In contemporary TAAA repairs, endarterectomy³⁰ or stenting²⁷ (or both) are used to treat visceral occlusive disease and enhance visceral perfusion. For many of our octogenarian patients, the decision to perform branch vessel intervention was determined intraoperatively; this was largely done to facilitate a secure anastomosis during branch vessel reattachment as the intimal layer may be heavily calcified or atherosclerotic. In the present study (Table 3), the proportion of octogenarians that required renal or visceral vessel endarterectomy or stenting or both was 58%; in extent II TAAA repairs, these procedures were performed in 85% of cases. In addition, the proportion of octogenarians that underwent renal or visceral vessel endarterectomy or stenting or both (58%) was significantly higher than the proportion of nonoctogenarians (33.6%, $P < .001$). Although endarterectomy has been associated with significantly less renal failure in patients with preexisting renal dysfunction,³⁰ it is difficult to assess whether or not our octogenarian cohort benefited in this regard, because nearly one quarter of patients experienced postoperative renal failure.

Despite the high percentage of octogenarian repairs that necessitated some form of branch vessel intervention, we did not find any increased risk of death after these procedures. Fifty-five of 88 octogenarians had either a renal bypass, renal endarterectomy, or a renal stent placed; there was no difference in early death between those who received a renal intervention (4/55, 25%) and those who did not (8/33, 24%; $P = 1.0$). Forty-three of 88 octogenarians had either left or right renal endarterectomy; there was no difference in early death between those who received renal endarterectomy (11/43, 26%) and those who did not (11/45, 24%; $P = 1.0$).

TABLE 6. Independent predictors of operative mortality and adverse outcome in 88 octogenarian patients after open thoracoabdominal aortic aneurysm repair: a multivariate stepwise logistic regression analysis

Variable	Odds ratio	P value
Operative mortality		
Extent II TAAA repair	11.6	.001
Aneurysm rupture	5.7	.02
Aortic dissection	5.6	.02
Adverse event*		
Aortic dissection	4.7	.03
Extent II TAAA repair	9.5	.002

TAAA, Thoracoabdominal aortic aneurysm. *Adverse event is a composite end point that was defined as the occurrence of any of the events including operative death, stroke, and permanent (at discharge) renal failure, paraplegia, or paraparesis.

Octogenarians experienced significantly higher rates of operative mortality, in-hospital death, and death within 30 days (Table 5) than nonoctogenarians. Although the outcome of extent IV repair in octogenarians was relatively similar to the outcome in nonoctogenarians, there was a remarkable difference between operative mortality after extent II repair in octogenarians (62%) versus nonoctogenarians (8.3%, $P < .001$). Furthermore, among octogenarians (Table 4), we found a pronounced difference in mortality rate by extent of repair; the operative mortality rate for extent II TAAA repair was approximately 6 times that of extent IV TAAA repair. It seems reasonable to reserve elective extent II repair for those octogenarians in extremely good health. Of the 5 early survivors in the group of 13 extent II repairs in octogenarians, none had a significant history of cardiac disease (no angina, no previous myocardial infarction, and no previous surgical or percutaneous cardiac revascularization), only 1 patient had a left ventricular ejection fraction less than 55%, and none had preoperative renal insufficiency. Disappointingly, of these 5 survivors, 2 developed permanent renal failure. These results warrant careful consideration of the usefulness of extent II TAAA repair in octogenarians, who may benefit more from alternative approaches.

In addition, adverse events and most of the postoperative complications analyzed were significantly greater in octogenarians than in nonoctogenarians (Table 5). Our study found that 23% of octogenarians experienced renal failure that required dialysis; this is consistent with a rate of 21% reported by Huynh and colleagues¹⁸ for TAAA and descending thoracic aneurysm repair in patients aged 79 years or older. We also found a trend toward more patients with postoperative paraplegia among octogenarians than nonoctogenarians. We speculate that these complications may be related to the dispersal of emboli in these heavily atherosclerotic octogenarians.

Among octogenarians (Table 4), extent II TAAA repairs were associated with more than twice the overall rate of adverse events (77% vs 36%, $P = .006$), almost 3 times as many patients with permanent paraplegia (23% vs 8%, $P = .05$), more than 3 times as many patients with renal failure requiring dialysis at discharge (69% vs 23%, $P = .001$), and more than 4 times as many patients with stroke (23% vs 6%, $P = .03$). Again, extent II TAAA repair in octogenarians should be approached cautiously.

In this series, survival for octogenarians was $64.5\% \pm 5.1\%$ at 6 months, $63.3\% \pm 5.2\%$ at 1 year (Figure 1), and $54.7\% \pm 5.4\%$ at 2 years; thus, if patients can survive the initial recovery period, they tend to do reasonably well the first 2 years after repair. Survival for nonoctogenarians was $88.4\% \pm 1.0\%$ at 6 months, $84.4\% \pm 1.1\%$ at 1 year, and $79.7\% \pm 1.2\%$ at 2 years. In a statewide analysis of elective repair, Rigberg and colleagues³¹ reported a 365-day mortality of 40% in octogenarians after TAAA

repair. Similarly, Huynh and colleagues¹⁸ reported a 48% mean 5-year survival after TAAA and descending thoracic aortic aneurysm repair in patients 79 years or older. From Crawford and DeNatale's¹ classic study on nonoperative treatment of 94 TAAA patients (with a median patient age of 66 years), we know that long-term survival without treatment is extremely poor (24% estimated survival at 2 years); in addition, more than half of these patients died as a result of aortic rupture. Despite our octogenarian group having significantly greater early mortality and lower long-term survival than nonoctogenarians, treatment supports the premise that the natural course of TAAA can be positively altered by surgical intervention. However, octogenarians face a lengthy recovery after repair; 35% ($n = 31$) of patients completed their recovery at a long-term acute care facility and 42% of those transferred subsequently died ($n = 13$).

Total endovascular approaches, and, to a lesser degree, hybrid endovascular TAAA repair are promising options for high-risk patients. Greenberg and colleagues³² reported outcomes regarding 406 completely endovascular TAAA repairs using branched endografts for extents I ($n = 16$), II or III ($n = 172$), and IV ($n = 218$). Early death was 13%, 5%, and 2%, and 2-year survival estimates were 70%, 74%, and 82%, respectively. Although median patient age and patient comorbidities were not reported, the authors justified the technical feasibility of this approach arguing that it was promising in patients considered high risk for open repair.³² Regarding hybrid TAAA repair, Hughes and colleagues³³ recently reported acceptable outcomes of 58 such repairs in TAAA extents I ($n = 3$), II ($n = 21$), and III ($n = 34$). The overall rates of operative mortality, stroke, and paraplegia were 9%, 0%, and 4%, respectively.³³ However, similar outcomes have not been replicated by other hybrid series and tend to be less acceptable.³⁴ A few centers restrict hybrid TAAA approaches to extents I, II, and III because the perceived risk of hybrid repair in extent IV is considered equivalent to the risk of open repair.^{35,36}

Currently, there is no commercially available US Food and Drug Administration–approved device for TAAA endovascular repair in the United States. The major limitation of endovascular approaches to TAAA repair in octogenarians is the lack of off-the-shelf devices. Because most endografts are tailor made and take several weeks to fabricate, this process would have to be adjusted to better serve the emergency needs of octogenarians, many of whom present with aneurysm rupture or acute symptoms. However, it is anticipated that further improvements in endovascular technology will facilitate such repair in elderly patients.

In conclusion, access to open TAAA repair should not be denied to octogenarians solely because of their age; such refusal would likely result in hastened death in acutely

symptomatic patients or in those with rupture. However, extent II TAAA repair should be performed with caution in the oldest old patients. In octogenarians, extent II carries the highest risk of operative mortality and postoperative complications. Extent I, III, and IV, however, can be performed with a considerably lower risk of mortality and morbidity, particularly for extent IV TAAA repairs. Appropriate patient selection, preoperative risk stratification, improved surveillance for patients with known aortic disease, and timely elective repair may reduce operative risk in octogenarians. In addition, such patients should be counseled about the possible need for an extended period of recovery after TAAA repair. New developments are required to further improve the outcomes of TAAA repair in octogenarians.

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References

- Crawford ES, DeNatale RW. Thoracoabdominal aortic aneurysm: Observations regarding the natural course of the disease. *J Vasc Surg.* 1986;3:578-82.
- Coselli JS, Bozinovski J, LeMaire SA. Open surgical repair of 2286 thoracoabdominal aortic aneurysms. *Ann Thorac Surg.* 2007;83:S862-4.
- Svensson LG, Crawford ES, Hess KR, Coselli JS, Safi HJ. Experience with 1509 patients undergoing thoracoabdominal aortic operations. *J Vasc Surg.* 1993;17:357-68.
- Crawford ES, Crawford JL, Safi HJ, Coselli JS, Hess KR, Brooks B, et al. Thoracoabdominal aortic aneurysms: preoperative and intraoperative factors determining immediate and long-term results of operations in 605 patients. *J Vasc Surg.* 1986;3:389-404.
- Coselli JS, LeMaire SA. Left heart bypass reduces paraplegia rates after thoracoabdominal aortic aneurysm repair. *Ann Thorac Surg.* 1999;67:1931-4.
- Coselli JS, LeMaire SA, Köksoy C, Schmittling ZC, Curling PE. Cerebrospinal fluid drainage reduces paraplegia after thoracoabdominal aortic aneurysm repair: Results of a randomized clinical trial. *J Vasc Surg.* 2002;35:631-9.
- Köksoy C, LeMaire SA, Curling PE, Raskin SA, Schmittling ZC, Conklin LD, et al. Renal perfusion during thoracoabdominal aortic operations: cold crystalloid is superior to normothermic blood. *Ann Thorac Surg.* 2002;73:730-8.
- LeMaire SA, Jones MM, Conklin LD, Carter SA, Criddell MD, Wang XL, et al. Randomized comparison of cold blood and cold crystalloid renal perfusion for renal protection during thoracoabdominal aortic aneurysm repair. *J Vasc Surg.* 2009;49:11-9.
- Schepens MA, Heijmen RH, Ranschaert W, Sonker U, Morshuis WJ. Thoracoabdominal aortic aneurysm repair: results of conventional open surgery. *Eur J Vasc Endovasc Surg.* 2009;37:640-5.
- Kulik A, Castner CF, Kouchoukos NT. Outcomes after thoracoabdominal aortic aneurysm repair with hypothermic circulatory arrest. *J Thorac Cardiovasc Surg.* 2011;141:953-60.
- LeMaire SA, Price MD, Green SY, Zarda S, Coselli JS. Results of open thoracoabdominal aortic aneurysm repair. *Ann Cardiothorac Surg.* 2012;1:286-92.
- Patel VI, Lancaster RT, Conrad MF, Cambria RP. Open surgical repair of thoracoabdominal aneurysms - the Massachusetts General Hospital experience. *Ann Cardiothorac Surg.* 2012;1:320-4.
- World Population Prospects: The 2012 Revision, Highlights and Advance Tables. New York: Department of Economic and Social Affairs, Population Division, United Nations; 2013.
- Arias E. United States life tables, 2008. *Natl Vital Stat Rep.* 2012;61:1-63.
- Girardi LN, Coselli JS. Repair of thoracoabdominal aortic aneurysms in octogenarians. *Ann Thorac Surg.* 1998;65:491-5.
- Craver JM, Puskas JD, Weintraub WW, Shen Y, Guyton RA, Gott JP, et al. 601 octogenarians undergoing cardiac surgery: outcome and comparison with younger age groups. *Ann Thorac Surg.* 1999;67:1104-10.
- Sagban T, Kocabas F, Balzer K, Durán M, Weis-Müller BT, Grabitz K, et al. Outcome of septuagenarians and octogenarians after open TAAA repair. *Ital J Vasc Endovasc Surg.* 2012;19:21-30.
- Huynh TT, Miller CC 3rd, Estrera AL, Porat EE, Safi HJ. Thoracoabdominal and descending thoracic aortic aneurysm surgery in patients aged 79 years or older. *J Vasc Surg.* 2002;36:469-75.
- Di Luozzo G, Shirali AS, Varghese R, Lin HM, Weiss AJ, Bischoff MS, et al. Quality of life and survival of septuagenarians and octogenarians after repair of descending and thoracoabdominal aortic aneurysms. *J Thorac Cardiovasc Surg.* 2013;145:378-84.
- Alexander KP, Anstrom KJ, Muhlbaier LH, Grosswald RD, Smith PK, Jones RH, et al. Outcomes of cardiac surgery in patients > or = 80 years: results from the National Cardiovascular Network. *J Am Coll Cardiol.* 2000;35:731-8.
- Bhamidipati CM, LaPar DJ, Fonner E Jr, Kern JA, Kron IL, Ailawadi G. Outcomes and cost of cardiac surgery in octogenarians is related to type of operation: a multiinstitutional analysis. *Ann Thorac Surg.* 2011;91:499-505.
- Krane M, Voss B, Hiebinger A, Deutsch MA, Wottke M, Hapfelmeier A, et al. Twenty years of cardiac surgery in patients aged 80 years and older: risks and benefits. *Ann Thorac Surg.* 2011;91:506-13.
- Overman DM, Jacobs JP, Prager RL, Wright CD, Clarke DR, Pasquali SK, et al. Report from the Society of Thoracic Surgeons National Database Workforce: clarifying the definition of operative mortality. *World J Pediatr Congenit Heart Surg.* 2013;4:10-2.
- LeMaire SA, Miller CC 3rd, Conklin LD, Schmittling ZC, Köksoy C, Coselli JS. A new predictive model for adverse outcomes after elective thoracoabdominal aortic aneurysm repair. *Ann Thorac Surg.* 2001;71:1233-8.
- Wong DR, Parenti JL, Green SY, Chowdhary V, Liao JM, Zarda S, et al. Open repair of thoracoabdominal aortic aneurysm in the modern surgical era: contemporary outcomes in 509 patients. *J Am Coll Surg.* 2011;212:569-79.
- Coselli JS, LeMaire SA, Weldon SA. Extent II repair of thoracoabdominal aortic aneurysm secondary to chronic dissection. *Ann Cardiothorac Surg.* 2012;1:394-7.
- LeMaire SA, Jamison AL, Carter SA, Wen S, Alankar S, Coselli JS. Deployment of balloon expandable stents during open repair of thoracoabdominal aortic aneurysms: a new strategy for managing renal and mesenteric artery lesions. *Eur J Cardiothorac Surg.* 2004;26:599-607.
- Johansson G, Markstrom U, Swedenborg J. Ruptured thoracic aortic aneurysms: a study of incidence and mortality rates. *J Vasc Surg.* 1995;21:985-8.
- Griep RB, Ergin MA, Galla JD, Lansman SL, McCullough JN, Nguyen KH, et al. Natural history of descending thoracic and thoracoabdominal aneurysms. *Ann Thorac Surg.* 1999;67:1927-30.
- Svensson LG, Crawford ES, Hess KR, Coselli JS, Safi HJ. Thoracoabdominal aortic aneurysms associated with celiac, superior mesenteric, and renal artery occlusive disease: methods and analysis of results in 271 patients. *J Vasc Surg.* 1992;16:378-89.
- Rigberg DA, McGory ML, Zingmond DS, Maggard MA, Agustin M, Lawrence PF, et al. Thirty-day mortality statistics underestimate the risk of repair of thoracoabdominal aortic aneurysms: a statewide experience. *J Vasc Surg.* 2006;43:217-22.
- Greenberg R, Eagleton M, Mastracci T. Branched endografts for thoracoabdominal aneurysms. *J Thorac Cardiovasc Surg.* 2010;140:S171-8.
- Hughes GC, Andersen ND, Hanna JM, McCann RL. Thoracoabdominal aortic aneurysm: hybrid repair outcomes. *Ann Cardiothorac Surg.* 2012;1:311-9.
- Moulakakis KG, Mylonas SN, Antonopoulos CN, Liapis CD. Combined open and endovascular treatment of thoracoabdominal aortic pathologies: a systematic review and meta-analysis. *Ann Cardiothorac Surg.* 2012;1:267-76.
- Black JH 3rd. Technique for repair of suprarenal and thoracoabdominal aortic aneurysms. *J Vasc Surg.* 2009;50:936-41.
- Patel R, Conrad MF, Paruchuri V, Kwolek CJ, Chung TK, Cambria RP. Thoracoabdominal aneurysm repair: hybrid versus open repair. *J Vasc Surg.* 2009;50:15-22.