The impact of preoperative chronic kidney disease on outcomes after Crawford extent II thoracoabdominal aortic aneurysm repairs

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ABSTRACT

Objective: To determine whether preoperative chronic kidney disease (CKD) is predictive of poor outcomes in patients who undergo Crawford extent II thoracoabdominal aortic aneurysm (TAAA) repair.

Methods: Data were collected from patients with CKD (defined as a preoperative estimated glomerular filtration rate <60 mL/min/1.73 m^2; n = 399) and without CKD (n = 604) who underwent extent II TAAA repair during 1991 to 2016. We used univariate, multivariable, and propensity score matching analyses to compare outcomes between these 2 groups.

Results: Compared with patients without CKD, patients who presented with CKD were older and had greater rates of comorbidities, including coronary artery disease, cerebrovascular disease, and peripheral vascular disease. Patients with CKD had higher rates of operative mortality and adverse events. After propensity analysis, patients with CKD had greater rates of adverse event and renal failure necessitating dialysis, but had comparable rates of operative death to patients without CKD. Multivariable modeling indicated that CKD independently predicted adverse event (relative risk ratio [RRR] = 1.61; $P = .01$) and renal failure (RRR = 1.86; $P = .02$) after repair. After adjustment for median age, patients with CKD had substantially worse mid-term survival than those without (23.9 ± 2.4% vs 48.5 ± 2.5% at 10 years; $P < .001$).

Conclusions: In patients who present with CKD, extent II open TAAA repair carries considerable risks of operative death and adverse events. Further investigation is needed to improve renal protection during such repair. (J Thorac Cardiovasc Surg 2018;156:2053-64)

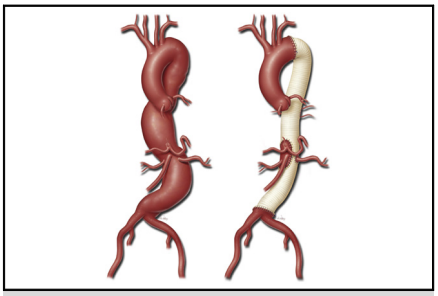

Illustration of a Crawford extent II thoracoabdominal aortic aneurysm repair.

Central Message

Outcomes after open Crawford extent II thoracoabdominal aortic aneurysm repair are poorer in patients with chronic kidney disease at the time of repair. Chronic kidney disease is predictive of adverse events.

Perspective

We present the results of 1003 Crawford extent II open thoracoabdominal aortic aneurysm repairs, 399 of which were performed in patients with chronic kidney disease (CKD). Patients with CKD had higher incidences of operative death and postoperative adverse events; however, after propensity analysis, they did not have a higher mortality rate. Analysis confirmed that CKD independently predicted adverse events.

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During the past several decades, the incidence of chronic kidney disease (CKD) has been increasing, and this increase is at least partly associated with the aging of contemporary populations.[1,2] Cardiovascular disease is a well-established complication of CKD[3,4]; specifically, patients with CKD are predisposed to pervasive and accelerated

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Abbreviations and Acronyms

CKD = chronic kidney disease
COPD = chronic obstructive pulmonary disease
CRP = cold renal perfusion
eGFR = estimated glomerular filtration rate
LHB = left heart bypass
RRR = relative risk ratio
TAAA = thoracoabdominal aortic aneurysm

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atherosclerosis, as well as multivessel cardiovascular disease.[5]

Extensive thoracoabdominal aortic aneurysm (TAAA) repair poses a risk of operative death and the development of postoperative paraplegia or renal failure necessitating dialysis; these complications, which have been long recognized, are commonly related to the distal ischemia that occurs during aortic clamping.[6,7] Many different techniques to provide renal protection during TAAA repair have been tried.[7-15] Our current approach evolved from the results of our 2 randomized clinical trials.[11,13] In the first trial, we established the benefit of renal perfusion with cold crystalloid instead of isothermic blood from the left heart bypass (LHB) circuit. In the second trial, we found no significant difference between using cold crystalloid or cold blood for renal perfusion; however, because cold crystalloid was associated with a trend toward lower paraplegia rates, as well as being easier to use, cold crystalloid is our preferred perfusate. Although progress has been made in developing methods of providing renal protection during TAAA repair,[11,13] this procedure remains problematic for patients undergoing the most extensive TAAA repair (Crawford extent II), particularly those who also have CKD.

To determine the importance of CKD as a preoperative consideration for patients who undergo extent II TAAA repair, we examined differences in operative outcomes among patients with CKD and those without CKD. We also attempted to determine whether CKD independently predicts poor outcomes, including operative mortality and other key adverse events.

METHODS

Study Enrollment and Patient Characteristics

Baylor College of Medicine's Institutional Review Board approved our clinical research protocol in 2006. For patients who underwent operation after protocol approval, clinical data were collected prospectively, and informed consent was obtained whenever possible. A waiver of consent was approved for patients who were unable to provide consent because of illness and who had no family members available who could provide consent for them. For patients who underwent surgery before the protocol was approved, the waiver of consent was approved, and data were collected retrospectively from medical records.

Between February 1991 and August 2016, 1115 consecutive extent II open TAAA repairs were performed on our single-practice service. We were unable to obtain consent from 2 patients (0.2%) who underwent TAAA repair after our protocol was approved; these patients were excluded from our analyses. Another 95 patients were excluded because data on preoperative estimated glomerular filtration rate (eGFR) were not available in the medical record, and 15 were excluded owing to a history of renal failure necessitating dialysis. The remaining 1003 TAAA repairs form the basis of this report.

Study Definitions and Follow-up

All data were collected using standard definitions, as reported recently.[6,16] The Chronic Kidney Disease Epidemiology Collaboration equation was used to calculate eGFR on the basis of preoperative serum creatinine level, age at repair, sex, and ethnicity.[17] In accordance with National Kidney Foundation Kidney Disease Outcome Quality Initiative guidelines,[2] CKD was defined as a preoperative eGFR <60 mL/min/1.73 m^2. According to this definition, 399 of the 1003 patients (39.8%) had preoperative CKD, and 604 (60.2%) did not. Postoperative acute renal dysfunction was defined as a peak postoperative serum creatinine level at least double the preoperative level or the need for dialysis.

Patients were considered symptomatic if they had symptoms associated with thoracoabdominal aortic disease, such as pain, hoarseness, or dysphagia. Repairs were divided into 3 eras based on the standardization of key surgical adjuncts: era 1, from 1991 to 1998, before adjuncts were standard practice; era 2, from 1999 to 2004, early adoption; and era 3, from 2005 to 2016, representing standardized contemporary use (Table E1).[6,10] Operative death was defined as death that occurred within 30 days of surgery or before final discharge from our hospital or any other hospital or long-term acute care facility to which a patient might have been transferred. Adverse event was defined as a composite endpoint comprising operative death or persistent (ie, present at hospital discharge) stroke, paraplegia, paraparesis, or renal failure necessitating dialysis.[18] Postoperative surveillance information was obtained through clinic visit, telephone interview, or written correspondence. The Social Security Death Index and internet obituary searches were used to identify deaths among patients who were lost to follow-up (n = 25).

Surgical Techniques

Our overall operative strategy has been largely standardized since 2005; our surgical approach and 30-year clinical practice are described more fully elsewhere.[6,16] Crawford extent II TAAA repair, the most extensive form of TAAA repair, typically involves replacing the aorta from just distal to the left subclavian artery to the aortic bifurcation and may extend into 1 or both iliac arteries. Extent II repair commonly necessitates the use of more protective adjuncts than less extensive TAAA repairs do. We routinely use moderate systemic heparinization (1.0 mg/kg), mild passive hypothermia (32°C to 34°C), LHB, cerebrospinal fluid drainage, selective reattachment of intercostal or lumbar arteries, and cold renal perfusion (CRP; 4°C). We selectively perfuse the celiac axis and superior mesenteric artery with isothermic blood by modifying the LHB circuit.[10] In CRP, cold (4°C) Ringer's lactate solution with mannitol (12.5 g/L) and methylprednisolone (125 mg/L) is delivered through 9-Fr Pruitt catheters as an initial bolus of 400 to 600 mL and then approximately every 6 to 10 minutes at a rate of 200 to 300 mL/min for 1 or 2 minutes (Figure 1). Body temperature is carefully monitored to avoid overcooling, with CRP delivery reduced as needed. If the rectal temperature is below

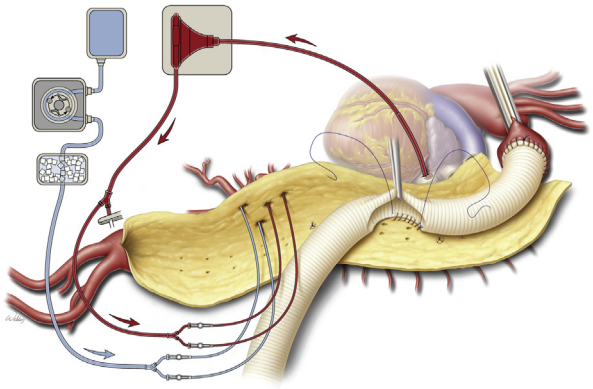


FIGURE 1. Drawing of cold renal perfusion (CRP) during Crawford extent II thoracoabdominal aortic aneurysm repair. After the proximal anastomosis is completed, the left heart bypass perfusion circuit is typically discontinued; the renal arteries are then cannulated with balloon perfusion catheters to enable intermittent perfusion with cold crystalloid solution through a separate CRP circuit. (Used with permission of Baylor College of Medicine.)

32°C, instead of administering CRP every 6 minutes, we increase the interval to every 12 to 18 minutes. If the rectal temperature is 31°C or the renal artery temperature is 15°C, we do not administer CRP. Although CRP has been provided to most patients since 2001, certain situations may preclude its use, such as some cases of rupture and emergent repair in which the renal circuit cannot be prepared before repair begins, hemodynamic instability, some cases of dissection extending into a renal artery, and other scenarios in which inserting a balloon catheter could be dangerous.

As appropriate, we manage the visceral and renal arteries with bypass grafts, endarterectomy, and stenting. In cases of chronic aortic dissection, residual dissection is managed distally by fenestration to clear away the dissecting membrane.[19] A multibranched TAAA graft may be used in cases of widely displaced visceral arteries or in patients with connective tissue disorders. In our early experience, we used the femoral artery as the arterial cannulation site during LHB; however, by 1996, we shifted to using the distal aorta as our standard site for cannulation whenever possible. In our practice, hypothermic circulatory arrest is rarely used and is reserved for aneurysms that cannot be safely clamped; likewise, a "clamp-and-sew" approach to extent II repair is rarely used, being reserved for aneurysms in which the patient's anatomy or clinical circumstances (eg, hemodynamic instability, rupture) preclude the use of LHB.

Statistical Analysis

Statistical analyses were performed with SAS version 9.4 (SAS Institute, Cary, NC), Stata version 13 (StataCorp, College Station, Tex), and R version 3.4.0 (R Project for Statistical Computing, Vienna, Austria). Continuous variables are presented as mean ± standard deviation or median [interquartile range (IQR)], as appropriate. Categorical variables are presented as number and percentage. Univariate comparisons were performed using the Pearson χ^2 test, Fisher exact test, or nonparametric Wilcoxon rank- sum test, as appropriate.

To identify independent predictors of operative death, adverse events, persistent paraplegia or paraparesis, and persistent renal failure necessitating dialysis after 1003 TAAA repairs, we built multivariable logistic regression models using clinically relevant preoperative and intraoperative factors that showed a univariate association with $P < .1$ for the event of interest (Table E2). As part of a subanalysis of the 399 repairs in the patients with CKD, we also built models to identify predictors of operative death, adverse events, and persistent renal failure necessitating dialysis (Table E3). We excluded a few variables that otherwise met the criteria for model entry because they were highly intercorrelated and then used a backward selection method with a removal P value of 0.05. A variance inflation factor ≥10 and clinical representability were considered. Model fit was assessed by the Hosmer–Lemeshow goodness-of-fit test and receiver operating characteristic curves. Postoperative complications were not entered into the models. Postoperative survival rates in those with and without CKD were estimated by the Kaplan–Meier method and compared by using log-rank test or Cox proportional hazard regression model adjusted for age. The assumption of proportional hazards was assessed by using the interaction term among predictors.

In addition, we analyzed outcomes using propensity-matched data for 311 pairs of patients with and without CKD. To conduct the propensity score matching, we matched observations within a ±0.2 caliper range. Balance of covariates in the matched data was assessed by using standardized differences (<.10) and propensity score histograms with kernel density curves. The validity of the propensity scores was confirmed using the Hosmer–Lemeshow test. We assessed the similarities between the profiles (eg, means or proportions between the 2 groups) and found that the patient profiles between the groups were within 10% of the standardized mean difference (Table 1). The following preoperative variables were included in propensity score matching: age, male sex, genetic disorder, chronic dissection, diabetes, coronary artery disease, cerebrovascular disease, history of chronic obstructive pulmonary disease (COPD)/emphysema/bronchitis, current tobacco use, acute symptoms, peripheral vascular disease, rupture, previous open distal aortic repair, and era.

RESULTS

Preoperative Characteristics

Compared with the patients without CKD, those with CKD were significantly older and had higher rates of additional comorbidities, including peripheral vascular disease (31.1% vs 18.7%; $P < .001$), coronary artery disease (34.1% vs 24.8%; $P = .001$), cerebrovascular disease (21.6% vs 13.7%; $P = .001$), and history of COPD, emphysema, or bronchitis (40.6% vs 24.0%; $P < .001$) (Table 1). In contrast, the patients without CKD had a higher prevalence of aortic dissection (61.6% vs 33.3%; $P < .001$), including more frequent DeBakey type I dissection, type III dissection, and chronic dissection. In addition, the patients without CKD had higher incidences of genetically triggered aortic disease (26.5% vs 4.0%), including Marfan syndrome (23.0% vs 3.8%; $P < .001$).

Operative Details

Patients with CKD had more overall visceral and renal procedures (ie, endarterectomy, stenting, or bypass) than those without CKD (54.6% vs 45.4%, $P = .004$). In particular, endarterectomy was required in more than one-third of patients with CKD (36.0% vs 18.9%; $P < .001$). Clamping proximal to the left subclavian artery (27.5% vs 16.5%; $P < .001$) and use of elephant trunk repair (10.1% vs 5.3%; $P = .006$) were more common in the non-CKD group. Intercostal/lumbar artery reattachment rates were higher in the non-CKD group (91.2% vs 77.9%; $P < .001$), suggesting that there were fewer suitable arteries for

TABLE 1. Preoperative characteristics of patients with and without CKD, overall, and propensity matched

Characteristic	Overall				Propensity matched cohort			
	All (n = 1003)	With CKD (n = 399)*	Without CKD (n = 604)	*P* value	All matched (n = 622)	With CKD (n = 311)*	Without CKD (n = 311)	Standard mean difference
Age, y	65 [55-72]	70 [64-74]	61 [48-68]	<.001	68 [62-72]	68 [62-72]	67 [63-72]	.006
Male sex	658 (65.6)	246 (61.7)	412 (68.2)	.04	412 (66.2)	206 (66.2)	206 (66.2)	.00
Genetic disorder	176 (17.5)	16 (4.0)	160 (26.5)	<.001	34 (5.5)	16 (5.1)	18 (5.8)	.02
Marfan syndrome	154 (15.4)	15 (3.8)	139 (23.0)	<.001	32 (5.1)	15 (4.8)	17 (5.5)	–
Aortic aneurysm without dissection	498 (49.7)	266 (66.7)	232 (38.4)	<.001	369 (59.3)	191 (61.4)	178 (57.2)	–
Aortic dissection	505 (50.3)	133 (33.3)	372 (61.6)	<.001	253 (40.7)	120 (38.6)	133 (42.8)	–
Acute or subacute	52 (5.2)	16 (4.0)	36 (6.0)	.20	28 (4.5)	11 (3.6)	17 (5.5)	–
Chronic	453 (45.2)	117 (29.3)	336 (55.6)	<.001	225 (36.2)	109 (35.0)	116 (37.3)	.05
DeBakey type I	212 (21.1)	36 (9.0)	176 (29.1)	<.001	87 (14.0)	33 (10.6)	54 (17.4)	–
DeBakey type III	284 (28.3)	91 (22.8)	193 (32.0)	.002	158 (25.4)	82 (26.4)	76 (24.4)	–
DeBakey type IIIa	32 (3.2)	13 (3.3)	19 (3.2)	.90	20 (3.2)	10 (3.2)	10 (3.2)	–
DeBakey type IIIb	252 (25.1)	78 (19.5)	174 (28.8)	.001	138 (22.2)	72 (23.2)	66 (21.2)	–
Localized dissection	9 (0.9)	6 (1.5)	3 (0.5)	.20	8 (1.3)	5 (1.6)	3 (1.0)	–
Maximum distal aortic diameter, cm	6.3 [5.7-7.3]	6.4 [5.9-7.3]	6.3 [5.6-7.3]	.20	6.4 [5.8-7.2]	6.3 [5.8-7.2]	6.5 [5.7-7.4]	–
Hypertension	866 (86.3)	368 (92.2)	498 (82.5)	<.001	557 (89.5)	286 (92.0)	271 (87.1)	–
Hyperlipidemia	264 (26.3)	116 (29.1)	148 (24.5)	.10	180 (28.9)	91 (29.3)	89 (28.6)	–
Diabetes	64 (6.4)	34 (8.5)	30 (5.0)	.02	41 (6.6)	24 (7.7)	17 (5.5)	.09
Coronary artery disease	286 (28.5)	136 (34.1)	150 (24.8)	.001	204 (32.8)	108 (34.7)	96 (30.9)	.09
Previous CABG	129 (12.9)	69 (17.3)	60 (9.9)	.001	99 (15.9)	58 (18.6)	41 (13.2)	–
Previous MI	166 (16.6)	83 (20.8)	83 (13.7)	.003	117 (18.8)	66 (21.2)	51 (16.4)	–
Cerebrovascular disease	169 (16.8)	86 (21.6)	83 (13.7)	.001	111 (17.8)	55 (17.7)	56 (18.0)	.008
Previous stroke	110 (11.0)	51 (12.8)	59 (9.8)	.10	74 (11.9)	34 (10.9)	40 (12.9)	–
Preoperative serum creatinine level, mg/dL	1.1 [0.9-1.3]	1.4 [1.2-1.7]	0.9 [0.8-1.1]	<.001	1.2 [0.9-1.4]	1.4 [1.3-1.7]	0.9 [0.8-1.1]	<.001
eGFR, mL/min/1.73 m^2	67 [50-87]	46 [37-54]	83 [70-96]	<.001	60 [47-75]	47 [37-54]	75 [67-87]	–
Body mass index, kg/m^2	26 [23-29] (n = 911)	26 [23-29] (n = 359)	26 [23-29] (n = 552)	.60	26 [23-29]	26 [23-30]	26 [23-29]	–
History of COPD/emphysema/ bronchitis	307 (30.6)	162 (40.6)	145 (24.0)	<.001	220 (35.4)	113 (36.3)	107 (34.4)	.04
Current tobacco use	781 (77.9)	349 (87.5)	432 (71.5)	<.001	535 (86.0)	265 (85.2)	270 (86.8)	.04
Symptomatic	622 (62.0)	242 (60.7)	380 (62.9)	.50	381 (61.3)	185 (59.5)	196 (63.0)	–
Acute	133 (13.3)	51 (12.8)	82 (13.6)	.70	76 (12.2)	38 (12.2)	38 (12.2)	0
Chronic	520 (51.8)	201 (50.4)	319 (52.8)	.50	324 (52.1)	155 (49.8)	169 (54.3)	–
Both acute and chronic	31 (3.1)	10 (2.5)	21 (3.5)	.40	19 (3.1)	8 (2.6)	11 (3.5)	–
Peripheral vascular disease	237 (23.6)	124 (31.1)	113 (18.7)	<.001	166 (26.7)	85 (27.3)	81 (26.0)	.03
Rupture	28 (2.8)	13 (3.3)	15 (2.5)	.50	16 (2.6)	7 (2.3)	9 (2.9)	.04
Previous open distal aortic repair†	175 (17.4)	85 (21.3)	90 (14.9)	.009	129 (20.7)	65 (20.9)	64 (20.6)	.008
Era				.005				.06
Era 1	289 (28.8)	115 (28.8)	174 (28.8)		191 (30.7)	86 (27.7)	105 (33.8)	
Era 2	329 (32.8)	152 (38.1)	177 (29.3)		204 (32.8)	114 (36.7)	90 (28.9)	
Era 3	385 (38.4)	132 (33.1)	253 (41.9)		227 (36.5)	111 (35.7)	116 (37.3)	

Values are reported as n (%) or median [interquartile range]. *CKD*, Chronic kidney disease; *IQR*, interquartile range; *CABG*, coronary artery bypass graft; *MI*, myocardial infarction; *eGFR*, estimated glomerular filtration rate; *COPD*, chronic obstructive pulmonary disease. *Preoperative eGFR <60 mL/min/1.73 m^2. †Previous open thoracoabdominal or abdominal aortic aneurysm repair.

TABLE 2. Operative details of 1003 extent II TAAA repairs stratified by CKD

Variable	All (n = 1003)	With CKD (n = 399)*	Without CKD (n = 604)	*P* value
Urgency of operation				
Elective	836 (83.3)	337 (84.5)	499 (82.6)	.40
Urgent	104 (10.4)	36 (9.0)	68 (11.3)	.30
Emergent	63 (6.3)	26 (6.5)	37 (6.1)	.80
Reverse elephant trunk	46 (4.6)	12 (3.0)	34 (5.6)	.052
Elephant trunk completion repair	82 (8.2)	21 (5.3)	61 (10.1)	.006
Clamping proximal to left subclavian artery	232 (23.1)	66 (16.5)	166 (27.5)	<.001
Intercostal/lumbar artery reattachment	862 (85.9)	311 (77.9)	551 (91.2)	<.001
Aortic clamp time, min	67 [55-82]	61 [52-77]	70 [59-85]	<.001
Management of visceral or renal arteries				
Bypass graft	338 (33.7)	127 (31.8)	211 (34.9)	.30
Use of a 4-branch graft	74 (7.4)	21 (5.3)	53 (8.8)	.04
Endarterectomy	258 (25.7)	144 (36.0)	114 (18.9)	<.001
Stenting	86 (8.6)	52 (13.0)	34 (5.6)	<.001
Endarterectomy, stenting, or bypass	492 (49.1)	218 (54.6)	274 (45.4)	.004
Adjuncts				
"Clamp-and-sew" repair	150 (15.0)	71 (17.8)	79 (13.1)	.047
Hypothermic circulatory arrest	16 (1.6)	4 (1.0)	12 (2.0)	.20
Left heart bypass	837 (83.4)	324 (81.2)	513 (84.9)	.10
Left heart bypass time, min	23 [18-29] (n = 830)	21 [16-27] (n = 320)	24 [20-30] (n = 510)	<.001
Cannulation site: distal aorta	762 (76.0)	298 (74.7)	464 (76.8)	.50
Cannulation site: femoral artery	65 (6.5)	21 (5.3)	44 (7.3)	.20
Cerebrospinal fluid drainage	651 (64.9)	255 (63.9)	396 (65.6)	.60
Cold renal perfusion	690 (68.8)	267 (66.9)	423 (70.0)	.30
Selective perfusion of visceral arteries	649 (64.7)	270 (67.7)	379 (62.7)	.10

Values are reported as n (%) or median [interquartile range]. *CKD*, Chronic kidney disease; *IQR*, interquartile range. *Preoperative estimated glomerular filtration rate <60 mL/min/1.73 m^2. The distal cannulation site was unknown in 10 repairs.

reattachment in the CKD group (Table 2); this corresponded to shorter aortic clamp times in the CKD group.

Early Outcomes

There were 94 operative deaths (9.4%) (Table 3). Although the majority (66.0%) of operative deaths occurred ≤30 days postoperatively, a substantial portion (34.0%) occurred after 30 days. Patients with CKD had higher rates of operative mortality (12.8% vs 7.1%; $P = .003$), adverse events (26.3% vs 13.4%; $P < .001$), persistent stroke (5.5% vs 1.8%; $P < .001$), and persistent paraplegia (7.3% vs 3.0%; $P = .002$) than those without CKD. Not surprisingly, the patients with CKD more often developed renal failure after the repair (14.8% vs 6.8% $P < .001$). Patients with CKD also had substantially greater postoperative rates of cardiac and pulmonary complications (41.4% vs 27.3%; $P < .001$ and 50.6% vs 36.4%; $P < .001$, respectively). Patients with CKD were far less likely than patients without CKD to be discharged to home after repair (59.6% vs 79.3%; $P < .001$).

When patients with CKD were stratified by receipt of CRP, we did not find that CRP prevented persistent renal failure; the rates of persistent renal failure were 10.5% for patients who received CRP and 14.4% for those who did not (28/267 vs 19/132; $P = .30$). Similarly, when patients without CKD were stratified by receipt of CRP, we did not find that CRP prevented persistent renal failure; the rates of persistent renal failure were 5.2% in patients who received CRP compared with 3.9% in those who did not (22/423 vs 7/181; $P = .50$). In addition, we reviewed the use of visceral artery management approaches in patients with CKD (n = 399) and found no difference between patients who underwent visceral artery manipulation and those who did not in terms of the development of persistent renal failure (14.9% [27/218] vs 11.0% [20/181]; $P = .80$).

After propensity score matching, patients with CKD had higher rates of adverse events (27% vs 18.6%; $P = .01$), renal failure necessitating dialysis (14.1% vs 8.7%; $P = .03$), cardiac complications (42.8% vs 33.4%; $P = .009$), and life-altering complications (18.1% vs 9.6%; $P = .005$). Patients with CKD also had significantly longer stays in the intensive care unit (median, 6 days [IQR, 4-11 days] vs 4 days [IQR, 3-8 days]; $P = .009$).

Multivariable modeling indicated that CKD independently predicted adverse events (relative risk ratio [RRR],

TABLE 3. Early outcomes

Variable	Total cohort (n = 1003) All (n = 1003)	With CKD (n = 399)*	Without CKD (n = 604)	P value	Propensity-matched cohort (n = 622) All (n = 622)	With CKD (n = 311)*	Without CKD (n = 311)	P value
Adverse event†	186 (18.5)	105 (26.3)	81 (13.4)	<.001	142 (22.8)	84 (27.0)	58 (18.6)	.01
Operative death	94 (9.4)	51 (12.8)	43 (7.1)	.003	65 (10.5)	34 (10.9)	31 (10.0)	.70
30-d	62 (6.2)	32 (8.0)	30 (5.0)	.049	45 (7.2)	23 (7.4)	22 (7.1)	.90
Stroke	43 (4.3)	29 (7.3)	14 (2.3)	<.001	31 (5.0)	20 (6.4)	11 (3.5)	.10
Persistent stroke‡	33 (3.3)	22 (5.5)	11 (1.8)	<.001	23 (3.7)	14 (4.5)	9 (2.9)	.30
Spinal cord deficit	134 (13.4)	70 (17.5)	64 (10.6)	.002	102 (16.4)	57 (18.3)	45 (14.4)	.20
Persistent paraplegia‡	47 (4.7)	29 (7.3)	18 (3.0)	.002	39 (6.3)	24 (7.7)	15 (4.8)	.20
Persistent paraparesis‡	30 (3.0)	11 (2.8)	19 (3.2)	.70	19 (3.1)	8 (2.6)	11 (3.5)	.50
Acute renal dysfunction	173 (17.2)	89 (22.3)	84 (13.9)	<.001	121 (19.5)	70 (22.5)	51 (16.4)	.054
Renal failure necessitating dialysis	100 (10.0)	59 (14.8)	41 (6.8)	<.001	71 (11.4)	44 (14.1)	27 (8.7)	.03
Persistent renal failure‡	76 (7.8)	47 (11.8)	29 (4.8)	<.001	52 (8.4)	32 (10.3)	20 (6.4)	.08
Cardiac complications	330 (4.8)	165 (41.4)	165 (27.3)	<.001	237 (38.1)	133 (42.8)	104 (33.4)	.009
Pulmonary complications	422 (42.1)	202 (50.6)	220 (36.4)	<.001	284 (45.7)	151 (48.6)	133 (42.8)	.20
Respiratory failure	304 (30.3)	150 (37.6)	154 (25.5)	<.001	210 (33.8)	111 (35.7)	99 (31.8)	.30
Necessitating tracheostomy	123 (12.3)	67 (16.8)	56 (9.3)	<.001	84 (13.5)	50 (16.1)	34 (10.9)	.07
Bleeding necessitating reoperation	37 (3.7)	18 (4.5)	19 (3.1)	.30	23 (3.7)	15 (4.8)	8 (2.6)	.20
Early survivors, n	909	348	561		557	277	280	
Life-altering complications§	92 (10.1)	54 (15.5)	38 (6.8)	<.001	77 (13.8)	50 (18.1)	27 (9.6)	.005
Length of ICU stay, d	4 [3-8] (n = 882)	6 [4-10] (n = 335)	4 [3-7] (n = 547)	<.001	5 [3-9] (n = 528)	6 [4-11] (n = 265)	4 [3-8] (n = 263)	.009
Length of hospital stay, d	13 [9-20] (n = 906)	15 [11-23] (n = 345)	12 [9-18] (n = 561)	<.001	13 [10-22] (n = 554)	15 [11-22] (n = 274)	12 [9-21] (n = 280)	.20

Values are reported as n (%) or median [interquartile range] unless otherwise noted. *CKD*, Chronic kidney disease; *ICU*, intensive care unit; *IQR*, interquartile range. *Preoperative estimated glomerular filtration rate <60 mL/min/1.73 m^2. †Defined as operative death or persistent (present at hospital discharge) stroke, paraplegia, paraparesis, or renal failure necessitating dialysis. ‡Present at the time of hospital discharge or early death. §Discharge with stroke, paraplegia, paraparesis, or renal failure necessitating dialysis.

1.61; $P = .01$) and renal failure necessitating hemodialysis (RRR, 1.86; $P = .02$) after repair, but CKD did not predict operative mortality (Table 4). CRP (RRR, 0.53; $P = .006$) and intercostal/lumbar artery reattachment (RRR, 0.46; $P = .003$) were predicted to reduce the risk of operative mortality. Rupture was highly predictive of persistent renal failure necessitating dialysis (RRR, 4.19; $P = .004$), persistent paraplegia or paraparesis (RRR, 4.07; $P = .003$), and adverse events (RRR, 3.25; $P = .004$). Operative mortality in the group of 267 patients with CKD who received CRP during repair was less than one-half that of the 132 patients with CKD who did not receive CRP (9.4% vs 19.7%; $P = .006$).

Of the 399 repairs in patients with CKD, multivariable modeling showed that CRP provided protection against operative death (RRR, 0.30; $P < .001$), as did reattachment of intercostal and lumbar arteries (Table 5). In contrast, visceral or renal artery stenting and a history of COPD, emphysema, or bronchitis increased the risk of operative death (RRR, 2.85; $P = .009$ and RRR, 2.17; $P = .02$, respectively). In the CKD group, previous stroke was the greatest predictor of adverse events (RRR, 1.94; $P = .04$), and rupture was a strong predictor of persistent renal failure necessitating dialysis (RRR, 4.33; $P = .04$).

Multisystem organ failure was the most common cause of operative death (n = 45; 48%) (Table 6). Although causes of death did not appear to differ substantially between the patients with CKD and those without CKD, multisystem organ failure with sepsis was more common in patients with CKD (n = 19 vs n = 11).

Late Outcomes

Clinical follow-up data were available for 883 of the 909 (97%) early survivors (348 with CKD and 561 without CKD); the median duration of follow-up was 5.7 years (IQR, 2.5-9.8 years). There were 519 late deaths; we were unable to identify the causes of these late deaths. Patients with CKD had substantially worse mid-term survival than those without CKD (53.2 ± 2.6% vs 72.2 ± 2.0% at 5 years and 23.9 ± 2.4% vs 48.5 ± 2.5% at 10 years; $P < .001$) (Figure 2, *A*). After adjustment for median age, the patients with CKD remained at a survival disadvantage (23.9 ± 2.4% vs 48.5 ± 2.5% at 10 years; $P < .001$) (Figure 2, *B*).

TABLE 4. Multivariable analysis of 1003 extent II TAAA repairs

Variable	Relative risk (95% CI)	*P* value
Operative death (n = 86)		
Symptomatic	2.34 (1.40-3.90)	.001
Stenting of visceral or renal arteries	2.25 (1.20-4.24)	.01
Chronic kidney disease	1.11 (0.69-1.78)	.70
Increasing patient age at repair, per y	1.05 (1.02-1.07)	<.001
Cold renal perfusion	0.53 (0.33-0.84)	.006
Intercostal/lumbar artery reattachment	0.46 (0.27-0.77)	.003
Adverse event (n = 186)*		
Rupture	3.25 (1.44-7.33)	.004
Chronic kidney disease	1.61 (1.12-2.30)	.01
Increasing patient age at repair, per y	1.05 (1.03-1.07)	<.001
Increasing aortic clamp time, per min	1.02 (1.01-1.03)	<.001
Intercostal/lumbar artery reattachment	0.37 (0.24-0.57)	<.001
Persistent paraplegia or paraparesis (n = 47)		
Rupture	4.07 (1.62-10.22)	.003
Coronary artery disease	1.79 (1.10-2.92)	.04
Chronic kidney disease	1.25 (0.76-2.05)	.40
Intercostal/lumbar artery reattachment	0.50 (0.28-0.87)	.01
Genetic disorder	0.33 (0.11-0.93)	.04
Renal failure necessitating dialysis (n = 76)		
Rupture	4.19 (1.56-11.20)	.004
Chronic kidney disease	1.86 (1.11-3.12)	.02
Increasing patient age at repair, per y	1.07 (1.04-1.10)	<.001
Increasing aortic clamp time, per min	1.02 (1.01-1.04)	<.001

CI, Confidence interval. *Defined as operative death or discharge with renal failure necessitating dialysis, paraplegia, paraparesis, or stroke.

TABLE 5. Multivariable analysis of 399 extent II TAAA repairs with CKD

Variable	Relative risk (95% CI)	*P* value
Operative death (n = 51)		
Stenting of visceral or renal arteries	2.85 (1.30-6.27)	.009
History of COPD/emphysema/bronchitis	2.17 (1.15-4.07)	.02
Left heart bypass	1.18 (0.52-2.70)	.70
Intercostal/lumbar artery reattachment	0.33 (0.17-0.63)	.001
Cold renal perfusion	0.30 (0.16-0.58)	<.001
Adverse event (n = 105)*		
Previous stroke	1.94 (1.03-3.68)	.04
Increasing aortic clamp time, per min	1.02 (1.01-1.03)	.001
Left heart bypass	0.81 (0.45-1.48)	.50
Cold renal perfusion	0.62 (0.38-1.01)	.06
Intercostal/lumbar artery reattachment	0.32 (0.19-0.56)	<.001
Persistent renal failure necessitating dialysis (n = 47)		
Rupture	4.33 (1.06-17.70)	.04
Increasing age at repair, per y	1.06 (1.02-1.11)	.008
Increasing aortic clamp time, per min	1.02 (1.01-1.04)	.002
Increasing eGFR, per mL/min/1.73 m^2	0.96 (0.93-0.99)	.003
Left heart bypass	0.73 (0.32-1.67)	.45
Cold renal perfusion	0.68 (0.35-1.32)	.30

CI, Confidence interval; *COPD*, chronic obstructive pulmonary disease; *eGFR*, estimated glomerular filtration rate. *Defined as operative death or discharge with renal failure necessitating dialysis, paraplegia, paraparesis, or stroke.

DISCUSSION

In patients undergoing extent II TAAA repair, those with CKD had considerably worse outcomes than those without CKD. Furthermore, CKD was found to be an independent predictor of adverse events and renal failure necessitating dialysis. Although the identification of CKD as a predictor of these key postoperative complications is not entirely surprising, our results indicate that CKD is a useful preoperative factor to assess and should be considered when counseling patients about the potential outcomes of open TAAA repair. Importantly, CKD is relatively easy to assess, and patients with CKD tend to have substantial comorbidities commonly considered to enhance risk during TAAA repair.[6,20] The well-established cardiovascular complications, as well as pervasive atherosclerosis, in patients with CKD may contribute to poor outcomes after extensive TAAA repair.[5]

The patients with CKD in our group were far older than the other patients and appeared more likely to present for extensive TAAA repair stemming from an atherosclerotic pathway, rather than from chronic aortic dissection or a connective tissue disorder. Specifically, CKD involves the development of secondary conditions, such as renal parenchymal hypertension and dyslipidemia, which then amplify the risk of atherosclerosis.[4] Thus, patients with CKD are more likely than those without CKD to develop cardiovascular disease and more likely to have worse outcomes.[21] Although the development of cardiovascular disease is considered multifactorial in origin, there is evidence implicating CKD itself as an independent risk factor for cardiovascular disease.[22-24] Furthermore, the increased atherosclerotic burden in patients with CKD can impact technical aspects of TAAA repair. For example, we reattached intercostal and lumbar arteries less

TABLE 6. Details regarding 94 operative deaths after 1003 extent II TAAA repairs

Variable	With CKD (n = 51), n	Without CKD (n = 43), n
Time of operative death		
POD ≤30	31	29
POD >30	20	14
Primary system(s) contributing to death		
Cardiac	6	4
Cerebral	6	6
Mesenteric	4	3
Pulmonary	2	5
Multisystem	26	19
With renal failure	16	15
With sepsis	19	11
With renal failure and sepsis	12	9
Unknown or other	6	5

CKD, Chronic kidney disease; *POD*, postoperative day.

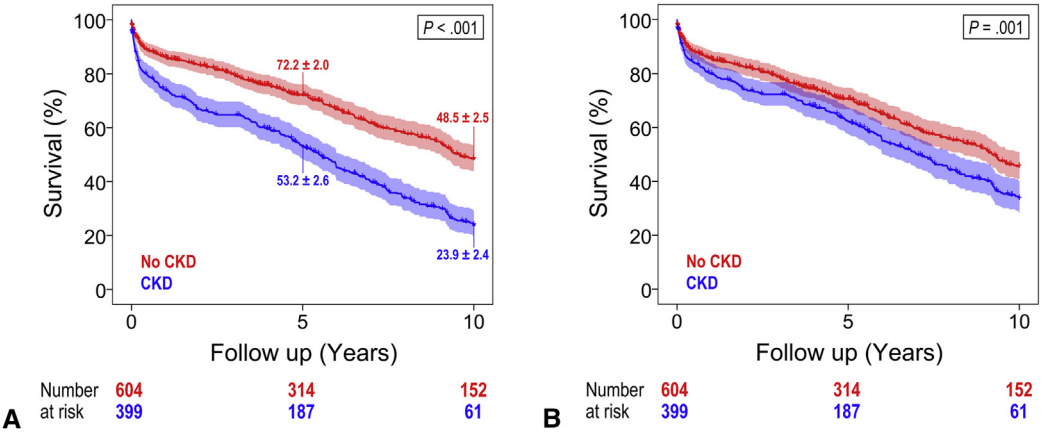


FIGURE 2. Estimated survival after 1003 extent II thoracoabdominal aortic aneurysm repairs stratified by chronic kidney disease (CKD) status (n = 399). A, Kaplan–Meier curve showing a survival disadvantage for patients with CKD ($P < .001$). B, When we adjusted for age using a Cox regression model to analyze survival, a survival disadvantage remained for those patients with CKD (hazard ratio [HR], 1.38; 95% confidence interval [CI], 1.14-1.66, $P = .001$). Each year of age also was associated with poorer survival (HR, 1.04; 95% CI, 1.03-1.05; $P < .001$). Survival curves were formulated from the data of all patients and include 94 operative deaths. CIs are shown in the shaded bands.

frequently in the CKD group, perhaps because there were fewer patients with patent vessels suitable for reattachment. Similarly, as expected, branch vessel endarterectomy, stenting, and bypass were performed much more often in the patients with CKD.

Interestingly, although CKD was an independent predictor of adverse events and renal failure necessitating dialysis, it was not a predictor of operative death. Of the 100 patients who experienced postoperative renal failure, 59 (59%) survived. Among the early survivors, 23 (39%) were taken off dialysis before discharge. Early survivors with postoperative renal failure had higher rates of CKD (61% vs 56.1%; $P = .60$) and CRP (71.2% vs 61%; $P = .30$) than patients who experienced operative death; however, neither of these findings is significant. The propensity score analysis supported the finding that patients with CKD did not have a greater rate of operative death. Survival after the development of postoperative renal failure may be associated with the increased use of CRP. In a multivariable analysis of all extent II repairs, CRP was protective against operative mortality but not against renal failure necessitating dialysis, supporting the hypothesis that CRP may offer a survival benefit for patients who develop postoperative renal failure. Conversely, CRP might have been identified as protective for operative mortality merely because of the small sample size of the operative death outcome itself; this possibility requires further investigation.

Although the impact of preoperative CKD (as defined by eGFR) on outcomes after extent II TAAA repair has not been specifically studied, the role of renal function on TAAA repair has been pursued by other investigators.[7,15,22,25,26] In 2017 report by Girardi and colleagues[25] of 202 patients with preoperative renal dysfunction (defined as serum creatinine >1.5 mg/dL or the need for dialysis) out of a total of 711 patients undergoing descending thoracic or TAAA repair, logistic regression analysis identified impaired renal function as a predictor of operative mortality; in addition, when the data were isolated for 96 extent II TAAA repairs, there was a substantial difference in operative mortality rate between the patients with renal disease and those without renal disease (28.5% vs 4.9%; $P = .001$). Predictive modeling by Safi and colleagues[26] showed that other variables prognostic of postoperative renal failure included preoperative creatinine level, providing visceral perfusion, left renal artery reattachment, and a "clamp-and-sew" approach to repair. Furthermore, in our recent report of our 30-year experience with all extents of TAAA repair, chronic renal insufficiency (serum creatinine level ≥3.0 mg/dL or requiring dialysis) was found to be an independent predictor of adverse events and operative mortality.[6]

Clearly, the role of patient-specific comorbidities, especially compromised renal function, plays a large role in the development of postoperative complications. Notably, aortic rupture was a stronger predictor than CKD in terms of predicting adverse event (RRR, 3.25 vs 1.61) and renal failure necessitating dialysis (RRR, 4.19 vs 1.86). Like CKD, rupture was not predictive of operative death, but it did predict persistent paraplegia or paraparesis (RRR, 4.07; $P = .003$). Although we have not seen dramatic improvements in the rates of postoperative renal failure from our previous study focused on 442 extent II TAAA repairs, we believe that the use of contemporary renal protective adjuncts is beneficial. Notably, patients with CKD who received CRP were only one-half as likely to die as those who did not receive it; analysis identified CRP as independently protective against operative mortality

(RRR, 0.30; $P < .001$). Rupture was highly predictive of renal failure necessitating dialysis in a subanalysis of patients with CKD (RRR, 4.33; $P = .04$).

Nonetheless, assessing the role of renal-specific protective adjuncts in TAAA repair is difficult, especially in patients with compromised renal function. The use of renal adjuncts tends to vary greatly between established centers: LHB, profound hypothermic circulatory arrest, the temperature of renal artery perfusion, and the solutions used for renal artery perfusion all vary.[7-9,12,14,15,25,26] This was highlighted by Svensson and colleagues' retrospective appraisal of E. Stanley Crawford's attempts to find predictors of reduced acute renal failure after 1233 descending thoracic or TAAA repairs.[7] In this analysis, the protection against developing acute renal failure provided by LHB, isothermic blood renal perfusion, and cold crystalloid renal perfusion were assessed; however, no protective relationship could be established—instead, preexisting renal dysfunction, along with diffuse atherosclerosis, the use of the LHB, and markers of hemodynamic instability were identified as independent predictors of acute renal failure.[7] To add confusion, others have also identified renal or visceral perfusion as predictive of adverse events.[25,26]

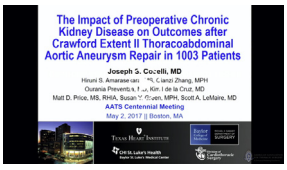
Perioperative management of patients with CKD relies on collaboration between the surgeon, intensivist, and nephrologist; multidisciplinary intensive care unit rounding is ideal. Primary aims are to ensure adequate mean arterial pressure and volume resuscitation, as well as to recognize developing cardiac, pulmonary, or infectious complications. We focus attention on maintaining glycemic control in patients with diabetes, careful monitoring of potassium and other electrolytes, and avoiding premature restarting of renin-angiotensin antagonists. Thoughtful consideration for intravascular access is maintained because hemodialysis access may eventually be needed. This includes avoiding peripherally inserted central catheters and subclavian venous lines, if possible, because they pose a risk of long-term venous stenosis.[27] After TAAA repair, the need for imaging before discharge is carefully balanced against the risk of contrast nephropathy. Every attempt is made to use the lowest possible volume of nonionic, iso-osmolar contrast agent. We wait until the serum creatinine level has returned as close to baseline as possible before imaging. Intravenous hydration with 1 L of crystalloid before the test and with another 500 mL afterward is routine. In patients deemed at higher risk, we add N-acetylcysteine to further reduce the risk of contrast nephropathy.[28]

Limitations of our study include the fact that our data come from a single practice, and our experience might not be universal. In addition, data were collected both retrospectively and prospectively from patients treated over a nearly 3-decade period, during which renal protection strategies and data collection procedures evolved substantially. The latter factor limits our ability to analyze the effect of surgical era on postoperative outcomes (as we have shown previously).[6,10] We believe that the propensity score matching analysis between the CKD and non-CKD groups is also subject to possible confounding, because patients with CKD are more likely to have preoperative atherosclerotic comorbidities, such as coronary artery disease, peripheral vascular disease, and so on. Even when matched for these preoperative atherosclerotic-based characteristics, it is difficult to tease apart the atherosclerotic origin of CKD; do the associated atherosclerotic comorbidities occur before the development of CKD, or does CKD predispose patients to the development of these comorbidities? Because this question has not been fully elucidated, the inferential power of the propensity score analysis may be limited. Moreover, we may have failed to capture all late deaths.

In conclusion, CKD as indicated by eGFR may be a useful tool in assessing individual risk among patients undergoing extensive aortic repair. Because patients with CKD tend to have many overlapping comorbidities that also tend to enhance operative risk, it may serve as a useful "primary marker" to identify patients at greatest operative risk. Patients with CKD face a substantial risk of postoperative complications after extensive TAAA repair; more than 25% of such patients will have a major adverse event after repair, and more than 15% will be discharged with a life-altering complication (eg, persistent stroke, paraparesis, paraplegia, new-onset renal failure necessitating dialysis). Preoperative counseling may help provide a realistic assessment of operative risk in patients with CKD that is balanced against the far greater risk presented by rupture in cases in which repair is inappropriately delayed. There remains a great need for new approaches to optimizing kidney protection during these extensive procedures.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://aats.blob.core.windows.net/media/17AM/2017-05-02/RM311/05-02-17_Room311_1442_Coselli.mp4.



Conflict of Interest Statement

J.S.C. participates in clinical research trials conducted by Glaxo Smith Kline and Bolton Medical; consults for,

receives royalties and a departmental educational grant from, and participates in clinical trials for Vascutek Terumo; and consults and participates in clinical trials for Medtronic and WL Gore & Associates. O.P. consults for and participates in clinical trials for Medtronic. S.A.L. has served as a consultant for Medtronic and Vascutek Terumo, an Advisory Board Member for Baxter Healthcare, a principal investigator for clinical studies sponsored by Vascutek Terumo and Baxter Healthcare, and a coinvestigator for clinical studies sponsored by Medtronic, WL Gore & Associates, Glaxo Smith Kline, Cook, and CytoSorbents. All other authors have nothing to disclose with regard to commercial support.

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Key Words: aneurysm (aorta), aortic operation, aortic dissection, thoracoabdominal, kidney disease, outcomes

Discussion

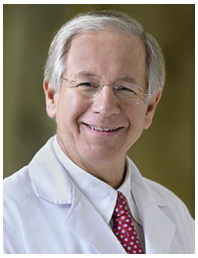
Dr L. Girardi *(New York, NY)*. Thank you for the privilege of discussing this paper. I would like to congratulate Dr Coselli and his team yet again for sharing with us their extensive experience on thoracoabdominal aneurysm repair. I am quite certain that we will never again see a presentation with more than 1000 extent IIs unless, of course, you come up with another analysis, in which case we will see that again at some point in the future.

To summarize, patients with chronic kidney disease, not surprisingly, were older with a much greater atherosclerotic burden and with COPD, similar to others who have looked at this process as well; in multivariable analysis, chronic kidney disease patients had a much higher incidence of

postoperative renal failure and need for hemodialysis, and a composite adverse event outcome of mortality, spinal cord injury, stroke, and dialysis. Surprisingly, mortality was not affected dramatically. Their 5- and 10-year survivals were compromised.

As you outlined, your group has spent a lot of time looking at renal protection in the past utilizing cold renal perfusion, crystalloid, and in 2 previous trials you had shown this to be a benefit as far as kidney preservation and also to be just as good as cold blood perfusion. If you look at the total cohort of patients here, 1003, in both groups, about 65% to 70% of the patients had cold renal perfusion as their primary renal protective strategy.

So given that in an extent II, for the most part, renal artery access is not an issue, what happened to the other 31%? Was it mostly from another era, perhaps in that first era I, or was it those patients who got cold blood perfusion were not included?



Dr J. Coselli (*Houston, Tex*). It's a combination of all those items, and thank you, Len, for your kind comments. In the early part of this series, we were not yet using cold crystalloid renal perfusion, and because the analysis is for the entire group, the lack of providing cold renal perfusion to nearly a third of cases is primarily related to the time this technique was adopted. Additionally, there were several years where we carried out 2 prospective randomized clinical trials, so that kept us from fully implementing this technique until these trials were completed. I believe this helps explain why cold renal perfusion of the kidneys was not used in more patients. Our contemporary use is a lot higher.

Dr Girardi. So basically if you have an extent II and even a III and a IV, for the most part you would advocate for using cold renal perfusion as often as you can?

Dr Coselli. We would and we do.

Dr Girardi. Thank you. My second question is, chronic kidney disease clearly predicted a higher incidence of postoperative renal failure on multivariable analysis; you had a relative risk of approximately 1.86. Interestingly, however, 24% of the patients who had postoperative need for dialysis subsequently recovered their renal function and left the hospital off dialysis, which is fairly gratifying.

When you look at the percentage of patients in each group, chronic kidney disease and those without kidney disease, those with it who developed postop need for dialysis had a lower rate of recovery than those without chronic kidney disease—again, not surprising. But was there a difference in your use of cold renal perfusion in those 2 recovering groups? Could you see a benefit in adding recovery, not just in the incidence of hemodialysis, but also in recovery if you used cold renal perfusion?

Dr Coselli. For the first part, we do not have the precise data on the number of patients discharged on hemodialysis who then came off hemodialysis; certainly, this has happened, but it is a limitation of our data that we just don't have concrete data on late (postdischarge) renal recovery. As you mentioned, there were 24 early survivors of extent II thoracoabdominal aortic aneurysm repair with chronic kidney disease that had postoperative renal failure, and, interestingly, 19 of those are dead now and 5 are still alive. We had 12 patients in each group (those with chronic kidney disease and those without) that recovered kidney function prior to hospital discharge; of these 24, 17 received cold renal perfusion and 7 did not (and of these 7, 6 received left heart bypass and 1 received hypothermic circulatory arrest). For those with chronic kidney disease who recovered (that is, postoperative renal dialysis was transient and did not persist to hospital discharge), 10 out of the 12 received cold perfusion and the other 2 had left heart bypass. For those without chronic kidney disease that underwent transient dialysis, 7 of 12 received cold perfusion.

However, the bottom line here is that despite the fact that we are analyzing a huge number of extent II TAAA repairs, when we get down to the specifics of renal recovery, the numbers are probably too small to make a statistically significant recommendation, but anecdotally, the trend is toward a favorable scenario when cold renal perfusion is used.

Dr Girardi. It is amazing that they recover after all that.

Dr Coselli. They do.

Dr Girardi. Patients with chronic kidney disease underwent a lot more adjunctive procedures, including stenting and endarterectomy and bypasses. In a previous study that you and Scott had done, you had shown that certainly in fragile renal arteries that underwent endarterectomy there was actually a higher incidence of postoperative dialysis if those procedures were performed in that population. Given that more than 50% of the patients in this series had those procedures, did those procedures predict better renal outcome in both groups and in the overall cohort, and then if so, do you advocate for doing that routinely if they have a lesion, or is there even a role for looking at these patients preoperatively and doing some things earlier, since 85% of them in fact are elective?

Dr Coselli. The trend is toward using these adjuvants; specifically, we advocate for renal artery stenting and endarterectomy if indicated. In the manuscript, we included the use of renal artery bypass grafts alongside renal artery stenting and endarterectomy in the renal artery reintervention variable; however, we actually use bypass grafts for different reasons. Bypass grafts are often used

in cases of chronic dissection when the anatomic origins of the arteries become displaced, and to reattach them properly, an interposition graft is helpful, whereas endarterectomy and stenting is focused on patients with renal artery occlusive disease, and so that actually confounds our analysis somewhat. But again, we would still recommend that in patients with renal artery stenosis, this condition should be dealt with intraoperatively.

Additionally, you raise a very interesting suggestion. It may be that in order to improve postoperative renal function in patients with chronic kidney disease, you would have to exclude patients with severe renal disease in acute crisis, including those who present with ruptures or other emergencies. Perhaps we should be thinking about renal disease more like we do coronary artery disease; maybe those patients with renal artery stenosis who have recoverable renal function (not those with unrecoverable function who might have a little peanut-sized kidney) should first undergo elective intervention on the kidney before undertaking extensive thoracoabdominal aortic aneurysm repair.

Dr Girardi. Thank you.

Dr S. Bolling *(Ann Arbor, Mich)*. Was there a separate group of patients that you operated on using deep hypothermia in the thoracoabdominal group and compared with those patients with renal failure?

Dr Coselli. We do not routinely use deep hypothermic circulatory arrest (HCA) for TAAA repair. In this series, we used deep HCA for specific and uncommon circumstances, such as when we cannot get proximal control of the descending thoracic aorta to place a cross-clamp on the aorta or for other anatomic reasons. In this series of extent II TAAA repairs, the numbers of cases where we used HCA was really too small to make any kind of statistical evaluation that made clinical sense.

TABLE E1. Era of surgical repair for 1003 extent II repairs stratified by CKD

Variable	All (n = 1003)	With CKD (n = 399)*	Without CKD (n = 604)	*P* value
Era of repair				.005
Era 1 (1991-1998)	289 (28.8)	115 (28.8)	174 (28.8)	
Era 2 (1999-2004)	329 (32.8)	152 (38.1)	177 (29.3)	
Era 3 (2005-2016)	385 (38.2)	132 (33.1)	253 (41.9)	

CKD, Chronic kidney disease. *Preoperative estimated glomerular filtration rate <60 mL/min/1.73 m^2.

TABLE E2. Variables entered into multivariable logistic regression models

Preoperative variables	Operative variables
Model for operative death	
Age at admission	Emergent repair
Symptomatic	Prior open distal aortic repair
Chronic dissection	Visceral or renal endarterectomy
Genetic disorder	Visceral or renal stenting
Chronic kidney disease	Intercostal reattachment
Cerebrovascular disease	Cold renal perfusion
Coronary artery disease	
Peripheral vascular disease	
Pulmonary disease	
Rupture	
*Model for adverse event**	
Age at admission	Emergent repair
Symptomatic	Visceral or renal bypass
Chronic dissection	Visceral or renal endarterectomy
DeBakey type I	Visceral or renal stenting
Genetic disorder	Aortic clamp time
Coronary artery disease	Intercostal/lumbar artery reattachment
Peripheral vascular disease	
Pulmonary disease	
Rupture	
Model for persistent paraplegia or paraparesis	
Age at admission	Emergent repair
Symptomatic	Visceral or renal endarterectomy
Chronic dissection	Clamp-and-sew
Genetic disorder	Intercostal/lumbar artery reattachment
Coronary artery disease	
Pulmonary disease	
Rupture	
Chronic kidney disease	
Model for persistent renal failure necessitating dialysis	
Age at admission	Visceral or renal bypass
Chronic dissection	Visceral or renal endarterectomy
Genetic disorder	Aortic clamp time
Diabetes	Intercostal/lumbar artery reattachment
Rupture	

*Adverse event is defined as operative death or discharge with renal failure necessitating dialysis, paraplegia, paraparesis, or stroke.

TABLE E3. Variables entered into multivariable logistic regression models for patients with CKD (n = 399)

Preoperative variables	Operative variables
Model for operative death	
Symptomatic	Elective repair
Previous stroke	Visceral or renal endarterectomy
Coronary artery disease	Visceral or renal stenting
History of COPD/emphysema/ bronchitis	Intercostal reattachment
	Cold renal perfusion
	Left heart bypass
*Model for adverse event**	
Previous stroke	Visceral or renal bypass
	Intercostal reattachment
	Cold renal perfusion
	Left heart bypass
	Aortic clamp time
Model for persistent renal failure necessitating dialysis	
Age at admission	Visceral or renal bypass
Rupture	Cold renal perfusion
eGFR	Left heart bypass
	Aortic clamp time

COPD, Chronic pulmonary obstructive disease; *eGRF*, estimated glomerular filtration rate. *Adverse event is defined as operative death or discharge with renal failure necessitating dialysis, paraplegia, paraparesis, or stroke. In univariate analysis, left heart bypass did not meet criteria for entering the three models and was forced into the model. Likewise, cold renal perfusion did not meet criteria for entering either the adverse event model or the persistent renal failure necessitating dialysis model and was forced into the model.