Incidence and risk factors of renal dysfunction after thoracic endovascular aortic repair

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Objectives: The risk of renal failure after thoracic endovascular aortic repair is not widely established. The aim of this study was to assess the incidence and risk factors of renal failure.

Methods: Between 1998 and 2008, 175 consecutive patients underwent 210 procedures at 2 tertiary academic institutions. Similar nephroprotective protocols and intravascular ultrasound were used. Retrospective analysis was performed. Generalized linear model was used to identify factors associated with change in postoperative estimated glomerular filtration rate.

Results: Underlying aortic diseases included 103 aneurysms, 72 dissections, 21 transections, and 14 penetrating ulcers. Median preoperative estimated glomerular filtration rate was $65 \text{ mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$. Contrast media averaged $108.7 \pm 69.8 \text{ mL}$. Median estimated glomerular filtration rates within 48 hours and 30 days were 69 and $67 \text{ mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$, respectively. Rates of acute renal dysfunction risk ($>25\%$ estimated glomerular filtration rate decrease), acute kidney injury ($>50\%$ estimated glomerular filtration rate decrease), acute kidney function failure ($>75\%$ estimated glomerular filtration rate decrease), and hemodialysis were 9.8% (19/193), 1.6% (3/193), 0% (0/193), and 0.5% (1/193), respectively. Rates of renal dysfunction at 1 month and 6 months were 13.3% (10/75) and 17.7% (6/34), respectively. Risk factors for acute renal dysfunction were intraoperative hypotension, stroke, sepsis, lengthy procedures, and number of stents; at 1 and 6 months they were increased age, male gender, African American race, diabetes mellitus, chronic pulmonary disease, smoking, and zone 0 to 1 graft deployment. Obesity was nephroprotective.

Conclusions: Thoracic aortic endograft has a significant rate of renal dysfunction; however, it is lower in this cohort than in previous smaller series. Routine use of intravascular ultrasound and reduced contrast may have contributed to lower rates of renal insufficiency. (J Thorac Cardiovasc Surg 2010;140:S161-7)

Thoracic endovascular aortic repair (TEVAR) has been increasingly applied for various aortic diseases as a promising alternative to the open surgical approach. Proposed advantages of TEVAR include shorter operative time, less blood loss, decreased need for general anesthesia, and shorter hospital stays.^{1,2} TEVAR avoids morbid thoracotomy and thoracoabdominal incisions, cardiopulmonary bypass, aortic crossclamping, and in some cases hypothermic circulatory arrest. Although TEVAR has a series of complications that

are unique to the endovascular procedures, there are morbidities such as renal dysfunction that are subject to both open and endovascular interventions. The risk of renal dysfunction after TEVAR has not been well studied. There is controversy in literature regarding the incidence of renal dysfunction after TEVAR of thoracic aortic diseases ranging from 1.5% to 34%.^{3,4} The goal of this study is to determine the incidence of acute and chronic renal failure after TEVAR and to identify associated risk factors.

METHODS

Patient Population

From October 1998 to May 2008, 175 consecutive patients underwent 210 TEVAR procedures for descending thoracic aortic aneurysms, descending thoracic aortic dissections (Stanford type B), penetrating thoracic ulcers, and traumatic aortic transection at 2 tertiary academic institutions (Harbor-UCLA Medical Center and University of Nebraska Medical Center). Fifty-seven of the 210 procedures involved patients who had previously undergone TEVAR and were analyzed further as a subgroup. All patients signed consent forms for the use of these investigational devices and agreed to participate in the surveillance protocols after deployment of the devices.

Inclusion and Exclusion Criteria

The study included patients with symptomatic aneurysms of the descending thoracic aorta, asymptomatic aneurysms of the descending thoracic aorta with at least twice the size of the proximal normal aorta,

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Abbreviations and Acronyms

ARF	= acute renal failure
CKD	= chronic kidney disease
CT	= computed tomography
eGFR	= estimated glomerular filtration rate
IQR	= interquartile range
IVUS	= intravascular ultrasound
RIFLE	= Risk of acute renal dysfunction, Injury to the kidney, Failure of kidney function, Loss of kidney function, End-stage kidney disease
TEVAR	= thoracic endovascular aortic repair

complicated acute Stanford type B aortic dissections, aneurysmal degeneration of chronic Stanford type B aortic dissections, symptomatic penetrating aortic ulcers, and traumatic aortic transections. Other inclusion criteria were signing the informed consent and agreeing to be followed up in the institutional surveillance program. Furthermore, the patient's arterial anatomy must have met device-specific requirements to be a candidate for TEVAR. Adequate proximal and distal landing zone and adequate-sized access vessels were evaluated before TEVAR was offered to the patients.

Exclusion criteria were applied to patients with diseases of the ascending aorta, connective tissue disorders, pregnancy, age below 18 years, systemic infection, and hypercoagulable state. Patients were also excluded if stent-graft placement was technically unsuccessful ($n = 3$), if they died in the operating room but before procedure initiation ($n = 2$), or if they were already undergoing dialysis before the procedure ($n = 6$).

Definitions

Aortic ulceration is defined an ulcer penetrating the elastic lamina into the tunica media associated with hematoma within the aortic wall. Acute aortic dissection is considered an acute event if it occurred within the first 14 days from onset of symptoms and as chronic if it occurred after 14 days. Aortic transection typically involves the intima and media, is nearly always transverse to the axis of the vessel, and may be complete or incomplete. The term "complicated dissection" was defined as persistent/unrelenting back pain despite maximal medical therapy, uncontrollable hypertension, aortic enlargement more than 5 mm per year, malperfusion syndromes, or (imminent) rupture.⁵ The patient's clinical health status was evaluated according to the classification of the American Society of Anesthesiologists.⁶ Baseline glomerular filtration rate was calculated with the abbreviated Modification of Diet in Renal Disease formula⁷ (estimated glomerular filtration rate [eGFR] [$\text{mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$] = $186 \times [\text{serum creatinine}]^{-1.154} \times [\text{age}]^{-0.203} \times [0.742 \text{ if female}] \times [1.210 \text{ if African American}]$). Chronic kidney disease (CKD) was defined as a baseline eGFR of $60 \text{ mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$ or less, and chronic renal failure was defined as eGFR of 30

TABLE 1. National Kidney Foundation classification of stages for CKD

Stage	Description	GFR
1	Kidney damage with normal or $\uparrow$ GFR	>90 (with CKD risk factors)
2	Kidney damage with mild or $\downarrow$ GFR	60–89
3	Moderate $\downarrow$ GFR	30–59
4	Severe $\downarrow$ GFR	15–29
5	Kidney failure	<15 (or dialysis)

CKD, Chronic kidney disease; GFR, glomerular filtration rate.

$\text{mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$ or less (stage III vs IV and V according to the Kidney Disease Outcome Quality Initiative)⁸ (Table 1). The most recent proposal for a consensus definition for acute renal failure (ARF) stems from the Acute Dialysis Quality Initiative group,⁹ which suggested criteria for 3 grades of increasing severity—risk of acute renal dysfunction (R), injury to the kidney (I), failure of kidney function (F)—and 2 outcome classes—loss of kidney function (L) and end-stage kidney disease (E) (Table 2). The RIFLE classification, based on eGFR and serum creatinine, was applied to postoperative diagnosis of acute renal dysfunction. Postprocedure RIFLE class R was defined accordingly as eGFR decline of more than 25% or serum creatinine increase $\times 1.5$ compared with baseline, RIFLE class I as eGFR decline of more than 50% or serum creatinine increase $\times 2$ compared with baseline, and RIFLE class F as eGFR decline of more than 75% or serum creatinine increase $\times 3$ compared with baseline or acute serum creatinine greater than 4 mg/dL, all based on nadir eGFR/peak creatinine values within 48 hours after the procedure. The patients' renal function was monitored postoperatively as an outpatient at 1 month and 6 months.

Imaging Protocol

The patients underwent computed tomographic (CT) scans using a 64-slice scanner with 3-mm collimation and 3:5 pitch. All patients except 6 underwent CT scans with electrocardiographic gating. Images were reconstructed using 50% overlap. All patients received Omnipaque (General Electric, Fairfield, Conn); 150 mL was injected at a rate of 3 mL/s using a power injector, and the scan was initiated 30 seconds after the start of the contrast injection. No trailing saline bolus was used. Approximately 20% of patients had CT scans performed at outside institutions, using similar protocols.

The intraoperative imaging included pulsed and regular fluoroscopy, as well as intravascular ultrasound (IVUS) (Volcano Therapeutics, Inc, Laguna Hills, Calif). The procedure was started with open exposure of pre-screened femoral artery, placement of a 9F sheath, and IVUS interrogation: the IVUS measures diameter of the ipsilateral (and if necessary contralateral) external and common femoral arteries. This is important to assure that the access vessel will accommodate the selected stent graft. Amount of calcification, intramural abnormalities, and tortuosity is also accurately assessed by IVUS. Next, the IVUS is advanced to the area of interest, where proximal and distal landing zones are evaluated for any thrombus or calcium. Next, by use of the IVUS, the diameters of the proximal and distal landing zones are measured, and the aortic branch vessels are marked on the fluoroscopic screen. Furthermore, the treatment length (distance between proximal and distal landing zones as well as any stent-graft overlap) is measured with IVUS by the pull-back method. With the information above, the appropriate stent grafts are chosen and introduced to the area of interest. A pre-deployment angiogram may be performed to reconfirm the location of the branch vessels (but this is not necessary). Subsequent to stent-graft deployment, the apposition of the graft and potential endoleaks are assessed by IVUS and treated with ballooning or

TABLE 2. RIFLE criteria for the classification of acute kidney injury

Class	GFR criteria
Risk	Plasma creatinine increase $1.5 \times$ baseline or GFR decline $> 25\%$
Injury	Plasma creatinine increase $2 \times$ baseline or GFR decline $> 50\%$
Failure	Plasma creatinine increase $3 \times$ baseline or GFR decline $> 75\%$ or acute plasma creatinine $> 4 \text{ mg/dL}$
Loss	Persistent ARF = complete loss of kidney function requiring dialysis for > 4 weeks but < 3 months
End stage	End-stage kidney disease requiring dialysis for > 3 months

RIFLE, Risk, Injury, Failure, Loss, End-stage kidney disease; GFR, glomerular filtration rate; ARF, acute renal failure.

additional stent grafts. A completion angiogram is then performed for confirmation.

The protocol for postoperative imaging includes a 3-phase multidetector CT angiogram. A noncontrast scan (baseline) through the chest and abdomen is followed by contrast CT angiography using 100 mL of nonionic contrast (arterial phase). A 2-minute delayed CT scan is performed (venous phase) to enhance detection rate for endoleaks. All elective patients underwent a 3-dimensional centerline-of-flow reconstruction to evaluate for access vessels and choose the appropriate stent graft based on proximal and distal landing zone and treatment length.

Periprocedural Management of Patients

All patients with baseline CKD stage II ($\text{eGFR} < 90 \text{ mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$) who underwent elective TEVAR received peri-interventional intravenous hydration with 0.9% saline solution, and all potentially nephrotoxic drugs were discontinued before the procedure. General anesthesia was used in 37% ($n = 77$) of the procedures and local/regional in 63% ($n = 133$). In brief, TEVAR was performed in an operating room equipped with a portable fluoroscopy or endovascular suite with a fixed imaging unit. Percutaneous femoral, radial, or brachial access was used to introduce an angiographic catheter proximal to the area of interest. Then, 40 mL of nonionic, hypoosmolar contrast medium (iohexol, Omnipaque) injected at flow rates of 20 mL/s using an automated power injector. In 43 (20%) patients an iliac conduit was necessary owing to small common femoral arteries. IVUS was used to interrogate the access vessel, the visceral and thoracic aorta, and its branches. The stent grafts were chosen on the basis of preoperative CT scan, intraoperative angiogram, and the IVUS measurements. Additional angiograms and IVUS interrogations were performed before and after deployment of the stent graft. Adenosine injections (36 mg followed by 18 mg for each subsequent dose) and right ventricular pacing were used for anti-impulsive therapy during deployment and balloon dilatation of the stent grafts in landing zone 2 and lower.

Statistical Analysis

Perioperative data including demographics, cardiovascular risk factors, preoperative renal function, operative technical details, intraoperative hemodynamic parameters and fluid balance details, and postoperative complications specifically for renal function as well as overall morbidity were summarized using descriptive statistics. Generalized linear model was used to evaluate these factors for an association with change in eGFR at various time points within follow-up. In the framework of generalized linear model, stepwise model selection procedure based on multiple criteria including Akaike information criterion, corrected Akaike information criterion, and Bayesian information criterion was applied to select the subset of factors, which has a statistically significant effect on the change of eGFR at different time points. A significance level of 5% was used for all analyses. The analyses were carried out using SAS version 9.2 (SAS Institute, Inc, Cary, NC).

RESULTS

A total of 175 consecutive patients underwent 210 endovascular procedures. Single repair was performed in 152 patients, whereas 23 had subsequent repairs. Of the 210 procedures, 132 (63%) were performed on male patients and 78 (37%) on female patients. Median age for the whole group was 70 years (interquartile range [IQR] 58–78 years). The majority of patients were evaluated as high-risk candidates for an open repair. The most commonly encountered comorbidities were hypertension (61%), smoking history (46%), coronary artery disease (29%), and previous aortic surgery (38%), as summarized in Table 3. Emergency TE-

TABLE 3. Demographics and comorbidities of patients treated by TEVAR

Characteristics	All patients (n = 210)
Age IQR (58–78 y)	70
Gender (male)	132 (62.9%)
Gender (female)	78 (37.1%)
Race (African American)	9 (4.2%)
Coronary artery disease	61 (29.1%)
Hypertension	128 (60.9%)
Acute myocardial infarction (<14 d)	7 (3.3%)
Congestive heart failure	17 (8.1%)
Diabetes mellitus	20 (9.5%)
Peripheral arterial disease	29 (13.8%)
Other vascular disease (vasculitis, Marfan)	5 (2.3%)
Preoperative stroke	21 (10%)
Chronic obstructive pulmonary disease	39 (18.5%)
Obesity (body mass index $\geq 30 \text{ kg/m}^2$)	11 (5.2%)
Hyperlipidemia	18 (8.5%)
History of smoking	96 (45.7%)
History of malignancy	10 (4.7%)
Hypercoagulable disorder	3 (1.4%)
Concomitant abdominal aortic aneurysm ($\geq 3 \text{ cm}$)	39 (18.5%)
Previous aortic surgery	80 (38.1%)
Previous cardiac surgery	22 (10.5%)
Previous trauma	11 (5.2%)

TEVAR, Thoracic endovascular aortic repair; IQR, interquartile range.

VAR was performed in 42 (20%) patients for contained aortic rupture and 29 (14%) patients were in meta-stable condition on arrival in the operating room. Proximal landing zone distribution was 2 and lower for 25% (52/210) of patients (Figure 1). The underlying disease of patients undergoing TEVAR is summarized in Table 4.

Renal Function

The stratification of preoperative renal function in the studied patient cohort, based on eGFR, is shown in Table 5. Only 24% (50/210) had normal preoperative renal function ($\text{eGFR} > 90 \text{ mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$), whereas 39% (81/210) had an eGFR less than $60 \text{ mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$ and 3% (6/210) were undergoing hemodialysis at the time of presentation. The average volume of procedural contrast used was $108.7 \pm 69.8 \text{ mL}$ (IQR: 60–150 mL). The median baseline eGFR was $65 \text{ mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$ (IQR 47–86 $\text{mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$). In the immediate postoperative period, the median eGFR was $69 \text{ mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$ (IQR: 46–95 $\text{mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$). At 30 days after the procedure, the median eGFR was $67 \text{ mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$ (IQR: 48–88 $\text{mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$) as shown in Table 5. After the renal function at 6 months there was a decrease in median eGFR to $59 \text{ mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$ (IQR: 41–95 $\text{mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$).

The rate of acute worsening in renal function from baseline was evaluated with the RIFLE criteria (Figure 2). We

FIGURE 1. Proximal landing zones for all patients undergoing thoracic endovascular repair. *Zone 0*, Covering the innominate artery; *zone I*, covering the left carotid artery; *zone II*, covering the left subclavian artery; *zone III*, involving the proximal one third of the descending thoracic aorta; *zone IV*, involving the distal two thirds of the descending thoracic aorta.

observed more than 25% acute decrease in eGFR in 19 (9.8%) of 193 patients, more than 50% decrease of eGFR in an additional 3 (1.6%), and there were no patients with greater than 75% decline in eGFR. However, a 65-year-old male patient with descending thoracic aortic aneurysm required postoperative hemodialysis (0.5%). He had baseline CKD stage 4, grade 4 aortic calcifications, and had an embolic frontal stroke and renal failure. He died on the seventh postoperative day.

At 1 month's follow-up, 10 (13.3%) of 75 patients had significantly worsening renal function; the observed rate at 6 months (Figure 3) was 17.7% (6/34), enough to be cat-

TABLE 4. Underlying pathology of patients undergoing TEVAR

Aortic pathology	n
Aneurysm	103 (49%)
Acute aortic dissection (≤ 14 d)	43 (20.5%)
Chronic aortic dissection (≥ 14 d)	29 (13.8%)
Aortic transection	21 (10%)
Penetrating ulcer	14 (6.7%)
Total	210

TEVAR, Thoracic endovascular aortic repair.

TABLE 5. Preoperative and postoperative renal function characteristics of patients undergoing TEVAR

Parameter	Median	IQR	n
Preop eGFR	65	47-86	204
Postop eGFR (24 h)	69	46-95	197
Postop eGFR (30 d)	67	48-88	75
Postop eGFR (6 mo)	59	41-95	34
Preoperative hemodialysis (chronic)	—	—	6
Total	—	—	210

TEVAR, Thoracic endovascular aortic repair; IQR, interquartile range; eGFR, estimated glomerular filtration rate ($\text{mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$).

egorized at a higher CKD stage on the basis of the National Kidney Foundation staging system. No additional patients began requiring hemodialysis in the follow-up period.

Statistical model selection procedure (multivariate analysis) was performed to identify factors associated with decreased eGFR ($P < .05$). Risk factors associated with acute decrease in eGFR were intraoperative hypotension, perioperative stroke, postoperative sepsis, and lengthy procedures. Increasing numbers of deployed stent grafts were also associated with decreased eGFR in correlation analysis. At 1 and 6 months, prognostic factors for worsening renal function included increased age, male gender, African American race, diabetes mellitus, hypertension, chronic obstructive pulmonary disease, smoking history, prior stroke or paraplegia, and arch zone 0 to 1 graft deployment. The analysis model identified obesity (body mass index $> 35 \text{ kg/m}^2$) as a nephroprotective factor ($P < .05$) for both

FIGURE 2. Rates of acute decline in renal function from baseline after TEVAR. RIFLE classification: *class R*, risk of acute renal dysfunction (eGFR decline $> 25\%$); *class I*, injury to the kidney (eGFR decline $> 50\%$); *class F*, failure of kidney function (eGFR decline $> 75\%$). AKI, Acute kidney injury; ARF, acute renal failure; HD, hemodialysis; TEVAR, thoracic endovascular aortic repair; eGFR, estimated glomerular filtration rate.

FIGURE 3. Rate of worsening renal function from baseline, at one and six months after TEVAR. *HD*, Hemodialysis; *eGFR*, estimated glomerular filtration rate; *TEVAR*, thoracic endovascular aortic repair.

short-term and long-term renal function after TEVAR (Table 6).

DISCUSSION

The emergence of TEVAR has been associated with lower rates of in-hospital morbidity and early mortality than those of open surgery in selected patient cohorts.^{3,10,11} However, the incidence of acute and chronic renal dysfunction in patients undergoing TEVAR has not been well defined. This is partially because there is no consistent definition for ARF used by various authors¹² and there is more than 1 parameter related to renal function monitoring. The absence of studies specifically designed to look into various parameters of renal function after TEVAR makes it difficult to compare rates of ARF reported by authors in various trials.^{3,11,13-17} These studies would use arbitrarily cutoff points for absolute or relative creatinine increase. To our knowledge, this is the only study using eGFR for follow-up after TEVAR. eGFR is a more sensitive indicator of renal function than creatinine and is recommended by Acute Dialysis Quality Initiative Group⁹ as well as Jin and coauthors.⁷ Furthermore, eGFR accounts for the variability of creatinine resulting from age, race, and gender and can be used as a risk factor to predict long-term survival.¹⁸

In regard to the immediate postoperative period, renal dysfunction was classified after the RIFLE criteria as suggested by the Acute Dialysis Quality Initiative Group.⁹ This grading system is sensitive to early changes in kidney function and is an independent predictor of hospital mortality in a large heterogeneous population of critically ill patients.¹⁹ Furthermore, in patients undergoing aortic arch replacement with hypothermic circulatory arrest, the RIFLE classification was able to readily identify acute kidney injury as risk factor for mortality.²⁰ The authors plead for widespread use of internationally accepted classifications

TABLE 6. Risk factors associated with decrease of eGFR acutely (24 hours) and at 1 month and 6 months

Prognostic factor	F value	P value
Twenty-four hours (n = 193)		
Gender (male)	5.25	.02331
Congestive heart failure	9.76	.00214
Smoking	4.56	.03432
Intraoperative hypotension	3.14	.07822
Adenosine	6.73	.01044
Postop bleed	0.00001	.99715
Hemodialysis	2.25	.13572
Coronary artery disease	8.62	.00385
Hypertension	3.28	.07209
Age	20.08	.00001
Blood urea nitrogen	35.78	.00000
Creatinine	11.06	.00111
PRBC (units of blood)	3.13	.07862
One month (n = 79)		
Gender (male)	7.90	.00645
Diabetes mellitus	6.81	.01108
Smoking	5.77	.01901
Race (African American)	5.05	.02784
Aortic arch zone	3.15	.03029
Age	20.00	.00003
Blood urea nitrogen	13.82	.00041
Six months (n = 37)		
Preoperative stroke	10.83	.00249
COPD	5.43	.02647
Stroke (intraop and postop)	20.36	.00009
Paraplegia	8.80	.00575
Arterial dissection/injury	7.65	.00944

eGFR, Estimated glomerular filtration rate; *PRBC*, packed red blood cells; *COPD*, chronic obstructive pulmonary disease.

for acute and chronic renal dysfunction in future studies. This allows for true “apple to apple” comparison of various studies on renal dysfunction.

The rate of acute worsening renal function remains high in survivors after TEVAR (11.9%). This includes a patient (0.5%) in the cohort who required postoperative hemodialysis. Preoperative poor renal dysfunction, intraoperative use of contrast material, perioperative hypotension, and aortic plaque embolization are some of the major reasons for this significant rate of worsening renal function. However, the overall rate of acute renal dysfunction after TEVAR in this study compares favorably with the results from other centers that used similar criteria for acute renal insufficiency. In a cohort of 97 patients, Eggebrecht and coauthors⁴ report ARF in 34% of patients after TEVAR (increase > 25% and/or > 0.5 mg/dL in pre-procedural serum creatinine at 48 hours), including 3% of patients in need of hemodialysis. The average use of 307 ± 188 mL of nonionic contrast medium is more than twice that in current study. In a series of 38 patients undergoing complex endovascular thoracoabdominal aneurysm repair, Chang and coworkers²¹ report 32% of patients with postoperative

acute renal insufficiency (increase $\geq 50\%$ in pre-procedural serum creatinine) and use of 170 ± 85 mL contrast.

Probable explanation for the lower renal dysfunction rate in the current study is the IVUS-guided TEVAR and reduced use of contrast material. Although the amount of contrast failed to reach statistical significance in the statistical analysis, the authors suspect that this study was underpowered to find the correlation. Inasmuch as the current study reports one of the lowest average amounts of contrast material used in any large-scale TEVAR study, the number of procedures needed to reach statistical significance is much higher than in most other published series. Contrast nephropathy is a widely recognized culprit for renal dysfunction, especially in patients with pre-existing renal insufficiency.²² IVUS-assisted TEVAR reduces the use of contrast material: IVUS assists with measurements of proximal and distal landing zones, gauging the access vessels and checking stent-graft apposition and any evidence of endoleaks. All these maneuvers reduce the intraoperative use of contrast. As described in the section on imaging protocol, IVUS may effectively reduce the contrast material to the amount needed for completion angiogram and management of any endoleaks. IVUS, along with fluoroscopy, provides almost all information given by angiogram. The study provides the lowest amount of contrast use in any large-scale TEVAR study, and the authors attribute this to systematic use of IVUS. Furthermore, IVUS allows for fewer wire manipulations and less risk of distal atheromatous microembolization. Thoracic and abdominal aortic stent grafting with fluoroscopy and IVUS is feasible in patients with advanced renal disease.^{23,24}

At 1 and 6 months, 13.3% and 17.7% of the patients progressed to a higher stage of chronic kidney injury, respectively. Other longitudinal follow-up for TEVAR using eGFR and standard kidney failure classification does not exist in the literature to allow for comparison. However there seems to be a persistent risk for renal insufficiency for several months after TEVAR. Possible causes for that include need for repeat contrast imaging to assess and follow up TEVAR for endoleak, along with progression of atherosclerotic disease.

The prognostic factors for worsening kidney function computed with multivariate analysis are TEVAR-related and patient-related. Advanced age, coronary artery disease, smoking, hypertension, and diabetes are known risk factors for atherosclerosis and therefore could affect renal function indirectly via progression of atherosclerotic disease or through increased intraoperative atheroemboli from wire and catheter manipulation. Preoperative eGFR was also a risk factor in our study group, as shown in previous studies.^{4,21} Optimization of the aforementioned comorbidities and adequate hydration of the patients at risk before TEVAR may decrease the risk of postoperative renal insufficiency. In fact, this is probably the reason for increase in median eGFR in the first 48 hours after

TEVAR; most patients underwent at least 24 hours of perioperative hydration. Intraoperative parameters, such as lengthy procedures, multiple stents, and more proximal deployment zones, all increased the risk of acute kidney injury likely by reflecting the need for more contrast and endovascular manipulations resulting in risk for contrast nephropathy, renal microembolism, and inflammatory response. Other prognostic factors identified, such as perioperative hypotension, bleeding, and sepsis, are likely related to ischemic kidney injury and should be treated promptly and aggressively. Therefore, optimization of the identified risk factors should be adopted as part of the patients' preparation for TEVAR and perioperative management.

Of interest, obese patients were less likely to have renal dysfunction in short- and mid-term follow-up, possibly reflecting the higher blood volume of that patient group, allowing for lower plasma concentration of contrast material and better volume reserve in case of blood loss.

There are multiple limitations to this study. It represents a retrospective analysis of prospectively collected data as part of an investigational protocol. There is no risk-adjusted control group. Furthermore, the follow-up on eGFR values is incomplete. This may limit the conclusions. One may raise the argument that the missing midterm and long-term eGFR data may have affected the results. A larger trial using a multicenter registry is recommended to substantiate the prognostic findings in this study.

In conclusion, worsening renal function is one of the most common morbidities after TEVAR. It is worrisome in this population with frequent imaging surveillance. The rate of renal dysfunction seems to be lower than in other studies, possibly owing to decreased use of contrast material and frequent IVUS imaging. Risk factors for deteriorating renal function were computed at 2 days, 1 month, and 6 months after TEVAR. Modification of identified perioperative risk factors may further decrease the incidence of renal dysfunction.

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