Published in final edited form as:

J Am Coll Surg. 2014 April ; 218(4): 797–805. doi:10.1016/j.jamcollsurg.2013.12.038.

Impact of Chronic Renal Insufficiency on the Early and Late Clinical Outcomes of Carotid Artery Stenting Using Serum Creatinine vs Glomerular Filtration Rate

Ali F AbuRahma, MD, FACS, Saadi Alhalbouni, MD, Shadi Abu-Halimah, MD, L Scott Dean, PhD, MBA, and Patrick A Stone, MD, FACS

Department of Surgery, Robert C Byrd Health Sciences Center, West Virginia University (AbuRahma, Alhalbouni, Abu-Halimah, Stone) and the Charleston Area Medical Center (Dean), Charleston, WV

Abstract

Background—This study analyzed the impact of chronic renal insufficiency (CRI) on early and late clinical outcomes of carotid artery stenting (CAS) using serum creatinine and glomerular filtration rate (GFR).

Study Design—There were 313 CAS patients classified into 3 groups: normal (serum creatinine <1.5 mg/dL or GFR ≥ 60 mL/min/1.73 m²); moderate CRI, and severe CRI (serum creatinine ≥ 3 or GFR < 30 mL/min/1.73 m²). Major adverse events ([MAE] stroke, death, and myocardial infarction) were compared for all groups.

Results—Using serum creatinine, perioperative stroke rates for normal, moderate, and severe CRI were: 5%, 0%, and 25%, respectively, ($p = 0.05$) vs 4.6%, 3.7%, and 11.1%, respectively, ($p = 0.44$) using GFR. The perioperative MAE rates for symptomatic patients were 9.3% and 0% ($p = 0.355$) and 2% and 5.9% ($p = 0.223$) for asymptomatic patients for normal and moderate/severe CRI, respectively, using serum creatinine vs 8.1% and 7.8%, respectively, for symptomatic patients and 2.5% and 3%, respectively, for asymptomatic patients using GFR. At a mean follow-up of 21 months, late MAE rates in normal vs moderate/severe CRI patients were 8.2% and 14%, respectively, ($p = 0.247$) using serum creatinine vs 6.6% and 13.3%, respectively, ($p = 0.05$) using GFR. Late MAE rates for symptomatic patients in normal vs moderate/severe CRI were: 8.7% vs 27%, respectively, ($p = 0.061$) using serum creatinine and 5.7% vs 18.8%, respectively, ($p = 0.026$) using GFR. Late death rate was 0.55% in normal vs 7.6% ($p = 0.002$) for moderate/severe CRI. Freedom from MAE at 3 years in symptomatic patients was 81% in normal and 46% in

Correspondence address: Ali F AbuRahma, MD, FACS, Department of Surgery, Robert C Byrd Health Sciences Center, West Virginia University, 3110 MacCorkle Ave, SE, Charleston, WV 25304. ali.aburahma@camc.org.

Disclosure Information: Nothing to disclose.

Presented at the Southern Surgical Association 125th Annual Meeting, Hot Springs, VA, December 2013.

Author Contributions Study conception and design: AbuRahma

Acquisition of data: Alhalbouni, Abu-Halimah, Stone

Analysis and interpretation of data: AbuRahma, Dean

Drafting of manuscript: AbuRahma, Stone

Critical revision: AbuRahma, Stone

moderate/severe CRI ($p = 0.0198$). A multivariate Cox regression analysis showed that a GFR of $< 60 \text{ mL/min/1.73 m}^2$ had an odds ratio of 1.6 ($p = 0.222$) of having a MAE after CAS.

Conclusions—The GFR was more sensitive in detecting late MAE after CAS. Carotid artery stenting in moderate CRI patients can be done with a satisfactory perioperative outcome; however, late death was significant.

Carotid artery stenting (CAS) has been viewed as an alternative to carotid endarterectomy (CEA) for treatment of carotid stenosis in symptomatic and asymptomatic patients, especially in those deemed high risk for surgical revascularization.^{1,2} There is strong evidence in the literature that suggests that patients with chronic renal insufficiency (CRI) have higher morbidity and/or mortality rates after CEA.³⁻¹² However, the effect of CRI on patients undergoing CAS, especially long-term outcomes, is not as well established, but a few studies have suggested that CRI does confer an increased risk.¹²⁻¹⁴

Only 2 previous studies^{12,14} have reported on the outcomes of CAS in patients with CRI using the glomerular filtration rate (GFR); one used the Modification of Diet in Renal Disease (MDRD) equation,¹² and the other used the Cockcroft-Gault equation.¹⁴ This study analyzed the impact of CRI on early and late clinical outcomes of CAS, using both serum creatinine levels and the GFR (MDRD).

Methods

This is a retrospective analysis of prospectively collected data on 313 CAS procedures (290 patients) that were done during a 10-year period (June 2001 through December 2011) at our institution. Only patients who had preoperative serum creatinine levels and/or GFRs using the MDRD equation were included in this analysis. This study was approved by the Institutional Review Board of Charleston Area Medical Center/West Virginia University. All patients were enrolled in carotid clinical trials of high-risk patients for CEA, as defined by the protocol of each trial, and included:

Parodi (Parodi Anti-Emboli System as an adjuvant cerebral protection device during carotid stent-supported angioplasty with the Boston Scientific Carotid Wall-stent Monorail Endoprosthesis, October 2001)

SHELTER (Stenting of High Risk Patients: Extracranial Lesion Trial with Emboli Removal, October 2001)

MAVERIC 1, 2, and 3 (Evaluation of the Medtronic AVE Self-Expanding Carotid Stent System with Distal Protection in the Treatment of Carotid Stenosis, July 2002)

CAPTURE (Carotid Rx Acculink/Rx Accunet Post-approval Trial to Uncover Unanticipated or Rare Events, July 2004)

VIVA (ViVEXX Carotid Revascularization Trial, November 2005)

CHOICE (Carotid Stenting for High Surgical-Risk Patients, October 2006)

EXACT (rapid exchange carotid stent system Xact with Emboshield protection system by Abbott Medical, August 2007)

Inclusion and exclusion criteria were outlined by each clinical trial. Overall, the indication for CAS included 50% symptomatic and 80% asymptomatic carotid artery stenosis. Demographic and clinical characteristics and intraoperative data were verified by a medical records review.

Patients were classified into 3 categories according to their renal function using serum creatinine levels and GFRs (based on the MDRD equation): normal renal function (a serum creatinine <1.5 mg/dL or a GFR ≥ 60 mL/min/1.73 m²), moderate CRI (serum creatinine 1.5 to 2.9 mg/dL or a GFR 30 to 59 mL/min/1.73 m²), and severe CRI (serum creatinine ≥ 3 mg/dL or a GFR < 30 mL/min/1.73 m²).

Carotid artery stenting protocol

All procedures were done in an independent invasive vascular laboratory with an Advanced Imaging System (General Electric System) located outside the cardiac catheterization laboratory and the operating room. All patients were given a regimen of 75 mg of clopidogrel (Plavix, Bristol-Myers Squibb/Sanofi Pharmaceutical Partnership) and 325 mg of aspirin daily for 3 to 5 days before the CAS procedure, followed by a dose of 325 mg of aspirin daily and 75 mg of clopidogrel after the procedure. Clopidogrel was continued for 6 weeks, and aspirin was continued indefinitely. All procedures were done using distal cerebral protection devices, according to their carotid trial protocols. Predilatation (3- to 4-mm balloons) was performed before filter insertion in most patients with tight stenosis. Postdilatation (using 5-mm balloons) was also performed after stent deployment to achieve optimal stent strut position.

All patients had immediate postoperative duplex ultrasounds that were repeated at 30 days and every 6 months. Long-term follow-up consisted of an examination of the patient in the Vascular Center of Excellence of our institution. All patients were examined for incidence of stroke or transient ischemic attacks during their follow-up. Postoperative cerebral MRI/CT scans were performed only on those with documented neurologic events (stroke/transient ischemic attacks).

Definition of endpoints

The primary endpoints were stroke, myocardial infarction (MI), and/or death. The combined major adverse events (MAE: stroke, MI, and death) were also determined. A minor stroke was defined as a neurologic deficit that persisted beyond 24 hours, resulting in grade I or II Rankin Scale, or a major stroke resulting in grades III through V Rankin Scale. A stroke was classified as ipsilateral if it affected the same cerebral hemisphere of the CAS, and contralateral if it affected the contralateral hemisphere. Myocardial infarction was defined as Q wave MI if seen in 2 or more leads, or non-Q wave MI was noted by an elevation of creatine kinase levels to greater than 3 times the upper limit of normal in the presence of elevated creatine kinase/myocardial bands (greater than the upper level of normal) and in the absence of new Qwave.

Statistical methods

Data analysis was performed using SAS 9.2. Comparisons of categorical variables were performed using a contingency table analysis with a Fisher's exact test or chi-square test to determine statistically significant differences. An ANOVA (analysis of variance) test or *t*-test was used to determine if any age differences existed among creatinine or GFR groups. Associations between the occurrence of a perioperative stroke and each risk factor were tested using Cox regression. Variables with significant associations using univariate analysis were subsequently tested with multivariate logistic regression. Freedom from stroke, MI, and death for both creatinine and GFR subgroups was estimated using a Kaplan-Meier curve analysis and compared using the log rank test. An alpha level = 0.05 was used to determine statistical significance.

Results

Three hundred thirteen CAS (290 patients) procedures were analyzed at a mean follow-up of 21 months (range 1 to 78 months). According to serum creatinine classifications, there were 262 CAS procedures in patients with normal renal function, 47 with moderate CRI, and 4 with severe CRI. This was in contrast to 196 CAS procedures in patients with normal renal function, 108 with moderate CRI, and 9 with severe CRI, according to GFR. Due to the low number of patients with a creatinine > 3 mg/dL, and a GFR < 30 mL/min/1.73 m², the demographic characteristics were classified according to patients with a serum creatinine < 1.5 mg/dL vs ≥ 1.5 mg/dL and, similarly, into a group with a GFR < 60 mL/min/1.73 m² vs ≥ 60 mL/min/1.73 m². Tables 1 and 2 summarize the demographic and clinical characteristics of patients according to renal function using serum creatinine and GFR. As noted from Table 1, patients with moderate and severe CRI had significantly more comorbidities: congestive heart failure (*p* = 0.040) and smoking (*p* = 0.025), according to serum creatinine. In Table 2, similar observations were also noted based on the GFR. The mean age was also statistically significantly different between various groups: a mean of 68.7 years (range 40 to 88 years) for patients with normal renal function, 74 years (range 48 to 88 years) for patients with moderate CRI (1.5 to 2.9 mg/dL), and 68 years (range 51 to 82 years) for patients with severe CRI (<3 mg/dL) according to the creatinine level.

Tables 3 and 4 summarize the perioperative complications according to renal function using serum creatinine levels (Table 3) or GFR levels (Table 4). As noted, when using the serum creatinine level, the perioperative stroke rates for patients with normal renal function, moderate, and severe CRI were: 5%, 0%, and 25%, respectively, (*p* = 0.05) and major adverse event (MAE) rates were 5%, 2.1%, and 25% respectively, (*p* = 0.179). This was in contrast to perioperative stroke rates of 4.6%, 3.7%, and 11.1%, respectively, (*p* = 0.44) and perioperative MAE rates of 4.6%, 4.6%, and 11.1%, respectively, (*p* = 0.666) when using GFR.

Tables 5 and 6 summarize the perioperative complications based on normal renal function vs moderate/severe CRI and preoperative indications. The perioperative stroke rates and MAE rates were 5% and 5% for patients with normal renal function vs 2% and 3.9% for patients with moderate/severe CRI (*p* = 0.481 and *p* = 1.0, respectively). A subgroup analysis using creatinine levels showed that the perioperative MAE rates were 9.3% and 0%, respectively,

($p = 0.355$) for symptomatic patients and 2% and 5.9%, respectively ($p = 0.223$) for asymptomatic patients with normal renal function vs patients with moderate/severe CRI, respectively (Table 5). This is in contrast to 8.1% and 7.8% ($p = 1$) for symptomatic patients, and 2.5% and 3% ($p = 1$) for asymptomatic patients, respectively, using GFR (Table 6).

At a mean follow-up of 21 months (range 1 to 78 months), the late MAE rates in patients with normal renal function vs those with moderate/severe CRI were 8.2% and 14%, respectively, ($p = 0.247$) using the serum creatinine level vs 6.6% and 13.3%, respectively, ($p = 0.055$) using GFR. The late MAE rates for symptomatic patients with normal renal function vs moderate/severe CRI were, respectively: 8.7% vs 27% ($p = 0.06$) using creatinine levels and 5.7% vs 18.8% ($p = 0.026$) using GFR. The late death rate was 0.55% in normal patients (GFR ≥ 60 mL/min/1.73 m²) vs 7.6% ($p = 0.002$) in patients with moderate/severe CRI (GFR < 60 mL/min/1.73 m²). Overall, there were 10 deaths in the whole series: 1 early death secondary to stroke and 9 late deaths secondary to congestive heart failure in 2, myocardial infarction in 2, cancer in 2, 1 acute renal failure, 1 due to an accident, and 1 unknown. Tables 7 and 8 summarize the late complications.

Cox regression analysis

A univariate analysis (Table 9) showed that a serum creatinine level ≥ 1.5 mg/dL had a hazard ratio of 1.2 (95% confidence interval [CI] 0.5 to 2.7 for MAE after CAS, $p = 0.674$); however, a GFR < 60 mL/min/1.73 m² had a hazard ratio of 1.6 (95% CI 0.9 to 3.1, $p = 0.127$). It should be noted that an asymptomatic indication for CAS had a hazard ratio of only 0.5 of having an MAE (95% CI 0.3 to 1, $p = 0.035$), but a CAS procedure that was done for post-CEA stenosis had a hazard ratio of 0.3 (95% CI 0.1 to 0.5, $p = 0.0002$). A multivariate analysis (Table 9) showed a serum creatinine ≥ 1.5 mg/dL had a hazard ratio of 0.95 (95% CI 0.4 to 2.5, $p = 0.918$) of having an MAE, while a GFR < 60 mL/min/1.73 m² had a hazard ratio of 1.6 (95% CI 0.8 to 3.3, $p = 0.222$). Asymptomatic indications for CAS had a hazard ratio of 0.6 (95% CI 0.3 to 1.1, $p = 0.095$), while CAS for post-CEA stenosis had a hazard ratio of 0.3 (95% CI 0.15 to 0.6, $p = 0.0006$).

Mid-term data/Kaplan-Meier curve analysis

As noted in Figures 1 and 2, freedom from stroke was not statistically significant between patients with a serum creatinine level ≥ 1.5 mg/dL vs a serum creatinine level < 1.5 mg/dL. The rate of freedom from stroke at 3 years was 85% for patients with normal renal function vs 97% for patients with a serum creatinine < 1.5 mg/dL ($p = 0.1811$). Similarly, as noted in Figure 2, the rate of freedom from stroke at 3 years for patients with a GFR ≥ 60 mL/min/1.73 m² was 84% vs 93% for patients with a GFR < 60 mL/min/1.73 m² ($p = 0.3127$). The rate of freedom from stroke, MI, and/or death (MAE) is shown in Figures 3 and 4, in which the rate of freedom from MAE at 3 years was 77% for patients with a serum creatinine < 1.5 mg/dL vs 73% for patients with a serum creatinine ≥ 1.5 ($p = 0.6273$), in contrast to 81% for patients with a GFR ≥ 60 mL/min/1.73 m² vs 68% for patients with a GFR < 60 mL/min/1.73 m² ($p = 0.1015$), as seen in Figure 4. Figures 5 and 6 show the freedom from stroke, MI, and/or death according to CAS indications, creatinine levels (Fig. 5), and GFR (Fig. 6). The rate of freedom from stroke, MI, and death at 36 months for symptomatic patients with

a serum creatinine < 1.5 mg/dL was 73% vs 53% for symptomatic patients with a serum creatinine > 1.5 mg/dL; and 80% for asymptomatic patients with a creatinine < 1.5 mg/dL vs 81% for asymptomatic patients with creatinine > 1.5 mg/dL ($p = 0.1544$). However, as noted in Figure 6, symptomatic patients with a $\text{GFR} < 60$ mL/min/ 1.73 m² had a 46% rate of freedom from stroke, MI, and/or death at 3 years vs 81% for symptomatic patients with a $\text{GFR} \geq 60$ mL/min/ 1.73 m² ($p = 0.0198$). The rate for asymptomatic patients was the same (81%) for patients with $\text{GFR} < 60$ mL/min/ 1.73 m² and ≥ 60 mL/min/ 1.73 m².

Discussion

The effects of CRI on perioperative outcomes in patients with carotid artery stenosis have been evaluated by multiple studies. Sidawy and colleagues³ retrospectively analyzed the National Surgical Quality Improvement Program (NSQIP) database regarding CEAs performed at 123 Veterans Affairs Medical Centers. Renal function was used to divide patients into 3 CRI groups: normal or mild (control, $\text{GFR} > 60$ mL/min/ 1.73 m²), moderate (GFR 30 to 59 mL/min/ 1.73 m²), and severe ($\text{GFR} < 30$ mL/min/ 1.73 m²). They characterized the risk factors associated with 30-day morbidity and mortality and noted that patients with moderate CRI were at an increased risk for cardiac events (1.7% vs 0.9%; $p < 0.001$) and pulmonary complications (2.1% vs 1.3%; $p < 0.001$) but not 30-day mortality ($p = 0.269$). However, no difference in the incidence of neurologic complications was noted (control, 1.7%; moderate CRI, 1.9%; severe CRI, 2.7%).

Kang and associates⁴ analyzed the NSQIP database for patients undergoing isolated CEA in private sector hospitals in an attempt to identify “high-risk” markers, and CEA was found to have favorable 30-day outcomes across a spectrum of patient comorbidities. The 30-day stroke rate was 1.6% and the death rate was 0.7%. Predictors of stroke were intraoperative transfusion (odds ratio [OR] 5.95; $p < 0.005$), previous major stroke (OR 5.34; $p < 0.0001$), shorter height (surrogate for small artery size; OR 1.09; $p < 0.010$), and increased anesthesia time (OR 1.02; $p < 0.008$). Critical limb ischemia (OR 12.72; $p < 0.0001$) and poor functional status (OR 7.05; $p < 0.0001$) were independent correlates of death. Of their patients, 16.2% had CRI (defined as serum creatinine > 1.5 mg/dL), and 0.9% were dialysis dependant. A univariate analysis did not show any difference in 30-day stroke rates between patients with CRI and patients with normal renal function (0.8% vs 1.7%; $p = 0.15$), but did show an increased mortality rate (1.5% vs 0.5%; $p = 0.007$).⁴

Unfortunately, most of the clinical trials that have analyzed the outcomes of CAS have excluded patients with CRI from their study population. Furthermore, the use of contrast during CAS may cause contrast-induced nephropathy and exaggerate CRI. In addition, dialysis patients are prone to bleeding and may require close observation if dual antiplatelets are used during or after stenting.

In an attempt to identify risk factors for poor outcomes in patients undergoing CAS, Jackson and coworkers¹³ evaluated the perioperative complications (major and minor stroke, myocardial infarction, femoral artery pseudoaneurysm, and death) after 215 CAS procedures. The rates of perioperative major and minor stroke were 0.5% and 2.8%, respectively. Chronic renal insufficiency was a predictor of perioperative complications,

including stroke; in fact, patients with a serum creatinine > 1.3 mg/dL had a 37% complication rate and an 11.1% stroke rate; those with normal renal function had a 13% complication rate ($p = 0.003$) and a 0.6% stroke rate ($p = 0.001$).¹³

Only 2 previous studies^{12,14} reported on the outcome of CAS in patients with CRI using GFR: one using the MDRD equation, and the other using the Cockcroft-Gault equation.¹⁴ Saw and colleagues¹⁴ reported on the outcomes of patients who underwent CAS at the Cleveland Clinic (1998 to 2003), who had their baseline creatinine and weight recorded. They used the Cockcroft-Gault equation to calculate creatinine clearance. Patients were grouped according to the presence or absence of chronic kidney disease ($\text{GFR} < 60 \text{ mL/min/1.73 m}^2$). They were divided into 4 groups, according to their creatinine clearance quartiles. Five hundred eighty-one patients who underwent CAS had data regarding creatinine clearance. They noted that patients with chronic kidney disease had a higher combined MAE rate (stroke, MI, and death) at 7 days (6.8% vs 2.7%, $p = 0.023$) and at 6 months (14.7% vs 5.6%, $p < 0.001$), compared with those without chronic kidney disease. The presence of chronic kidney disease was also associated with a higher stroke rate (4.2% vs 0.8%, $p = 0.009$) and death rate (8.4% vs 3.4%, $p = 0.015$) at 6 months compared with no chronic kidney disease. The 6-month Kaplan-Meier MAE-free survival was significantly higher among those without chronic kidney disease vs those with chronic kidney disease ($p < 0.001$). When the outcomes were compared according to creatinine clearance quartiles, the highest creatinine clearance quartile (fourth quartile) was associated with a lower combined MAE rate at both 7 days (1.4% vs 6.2%, $p = 0.049$) and at 6 months (4.1% vs 14.5%, $p = 0.004$), compared with the lowest creatinine clearance quartile. A Cox regression analysis also showed previous MI, chronic kidney disease, age, diabetes, and baseline hemoglobin as univariate predictors of 6-month combined MAE rates; however, a multivariate analysis showed only diabetes and chronic kidney disease as independent predictors of 6-month combined MAE rates.

Similar findings were noted in a recent analysis by Pro-tack and colleagues,¹² who evaluated the influence of CRI on outcomes after all modalities of carotid revascularization. Patients were stratified based on GFR using the MDRD equation. The overall 30-day morbidity and mortality rates were 16.9% and 1.1%, respectively. Twenty-eight percent of patients had moderate CRI and 6% had severe CRI. The 30-day stroke rates for these groups were 2.98%, 2.67% and 5.45% for normal renal function, moderate CRI, and severe CRI, respectively ($p = 0.54$). The 30-day mortality rates between the groups were 0.66% (normal renal function), 1.15% (moderate CRI), and 5.45% (severe CRI) ($p = 0.005$). For CEA patients, no difference in freedom from stroke existed between the various groups. However, for carotid angioplasty and stenting, patients with severe CRI showed significantly lower rates of freedom from stroke. Overall, patients with moderate CRI had similar outcomes, in contrast to those with severe CRI, who had significantly higher 30-day mortality rates after carotid revascularization.¹²

In our study, we analyzed the effect of renal function using 2 markers— serum creatinine and GFR/MDRD—on perioperative and long-term outcomes after CAS. We noted that more patients fell into the moderate/severe CRI group when GFR was used as the marker for renal function instead of serum creatinine.

In the perioperative period, we did not notice any significant difference in the rate of stroke in patients with normal renal function, compared with patients with moderate/severe CRI, whether renal function was based on serum creatinine or GFR ($p = 0.481$ and $p = 0.895$, respectively). However, there was a higher stroke rate for severe CRI patients (25%) vs normal patients (5%) when preoperative serum creatinine was used and 11.1% vs 4.6% when the GFR was used; although the p value was not significant (partly because of the sample size). Similarly, there was no significant difference in the rate of MAE for normal patients vs patients with moderate/severe CRI ($p = 1.0$ and $p = 0.83$, respectively). Also, renal status had no significant effect on outcomes in either symptomatic or asymptomatic patients.

In long-term follow-up, patients with moderate/severe CRI had a higher risk of death (7.6% vs 0.55%, $p = 0.002$) when GFR was used in the analysis; and, similarly, symptomatic patients with moderate/severe CRI had a higher chance of MAE (18.8% vs 5.7%, $p = 0.026$). However, these differences were not significant when serum creatinine was used as the marker for renal function. A Kaplan-Meier curve analysis also showed that symptomatic patients with moderate/severe CRI had significantly lower rates of freedom from MAE at 3 years using the GFR (46% vs 81%).

There is a potential limiting bias in our study. Patients with CRI are more likely to be admitted for preprocedure hydration and contrast nephropathy prophylaxis. Similarly, the interventionalist is more likely to use contrast more judiciously in these patients. Unfortunately, not all of the data regarding contrast nephropathy prophylaxis and the amount of contrast used were available to us. There were also a limited number of patients with serum creatinine > 3.0 mg/dL; therefore, we combined the late outcomes for patients with moderate and severe CRI and compared them with patients with normal renal functions.

Conclusions

Chronic renal insufficiency had no effect on perioperative outcomes after CAS, whether GFR or serum creatinine was used to determine renal function. The GFR was more sensitive, however, in predicting late MAE, especially in symptomatic patients. Carotid artery stenting can be performed in patients with moderate/severe CRI with satisfactory perioperative results. However, the late death rate was significantly higher in these patients, and late MAEs were also significantly high, especially in symptomatic patients, and should be regarded when considering CAS in these patients.

References

1. Mantese VA, Timaran CH, Chiu D, et al. The carotid revascularization endarterectomy versus stenting trial (CREST): Stenting versus carotid endarterectomy for carotid disease. *Stroke*. 2010; 41:S31–S34. [PubMed: 20876500]
2. Yadav JS, Wholey MH, Kuntz RE, et al. Protected carotid-artery stenting versus endarterectomy in high-risk patients. *N Engl J Med*. 2004; 351:1493–1501. [PubMed: 15470212]
3. Sidawy AN, Aidinian G, Johnson ON III, et al. Effect of chronic renal insufficiency on outcomes of carotid endarterectomy. *J Vasc Surg*. 2008; 48:1423–1430. [PubMed: 18829214]

4. Kang JL, Chung TK, Lancaster RT, et al. Outcomes after carotid endarterectomy: Is there a high-risk population? A National Surgical Quality Improvement Program report. *J Vasc Surg.* 2009; 49:331–338. [PubMed: 19216952]
5. Plecha EJ, King TA, Pitluk HC, Rubin JR. Risk assessment in patients undergoing carotid endarterectomy. *J Cardiovasc Surg.* 1993; 1:30–32.
6. Hamdan AD, Pomposelli FB, Gibbons GW, et al. Renal insufficiency and altered postoperative risk in carotid endarterectomy. *J Vasc Surg.* 1999; 29:1006–1011. [PubMed: 10359934]
7. Sternbergh WC III, Garrad CL, Gonze MD, et al. Carotid endarterectomy in patients with significant renal dysfunction. *J Vasc Surg.* 1999; 29:672–677. [PubMed: 10194495]
8. Shekherdimian RT, Golchet P, Moore W. The safety of carotid endarterectomy in patients with preoperative renal dysfunction. *Ann Vasc Surg.* 2002; 16:176–180. [PubMed: 11972248]
9. Ascher E, Marks NA, Schutzer RW, Hingorani AP. Carotid endarterectomy in patients with chronic renal insufficiency: a recent series of 184 cases. *J Vasc Surg.* 2005; 41:24–29. [PubMed: 15696039]
10. Debing E, van den Brande P. Chronic renal insufficiency and risk of early mortality in patients undergoing carotid endarterectomy. *Ann Vasc Surg.* 2006; 20:609–613. [PubMed: 16741650]
11. Tarakji A, McConaughy A, Nicholas GG. The risk of carotid endarterectomy in patients with chronic renal insufficiency. *Curr Surg.* 2006; 63:326–329. [PubMed: 16971203]
12. Protack CD, Bakken AM, Saad WE, Davies MG. Influence of chronic renal insufficiency on outcomes following carotid revascularization. *Arch Surg.* 2011; 146:1135–1141. [PubMed: 21690437]
13. Jackson BM, English SJ, Fairman RM, et al. Carotid artery stenting: identification of risk factors for poor outcomes. *J Vasc Surg.* 2008; 48:74–79. [PubMed: 18502085]
14. Saw J, Gurm HS, Fathi RB, et al. Effect of chronic kidney disease on outcomes after carotid artery stenting. *Am J Cardiol.* 2004; 94:1093–1096. [PubMed: 15476637]

Abbreviations and Acronyms

CAS	carotid artery stenting
CEA	carotid endarterectomy
CRI	chronic renal insufficiency
GFR	glomerular filtration rate
MAE	major adverse events
MDRD	Modification of Diet in Renal Disease
MI	myocardial infarction
OR	odds ratio

Figure 1.
Freedom from stroke based on serum creatinine levels.

Figure 2.
Freedom from stroke based on glomerular filtration rate (GFR) levels.

Figure 3.
Freedom from stroke/myocardial infarction (MI)/death based on serum creatinine levels.

Figure 4. Freedom from stroke/myocardial infarction (MI)/death based on glomerular filtration rate (GFR) levels.

Figure 5. Freedom from stroke/myocardial infarction (MI)/death by carotid artery stenting (CAS) indication and creatinine.

Figure 6. Freedom from stroke/myocardial infarction (MI)/death by carotid artery stenting (CAS) indication and glomerular filtration rate (GFR).

Table 1
Demographic/Clinical Characteristics and Renal Function Based on Serum Creatinine Levels

Variable	Normal (<1.5 mg/dL)	Moderate/severe CRI (≥ 1.5 mg/dL)	p Value
Carotid artery stenting, n	262	51	
Hypertension, n (%)	226 (86)	45 (88)	0.705
Coronary artery disease, n (%)	198 (76)	44 (86)	0.095
Congestive heart failure, n (%)	53 (20)	17 (33)	0.040
Diabetes mellitus, n (%)	124 (47)	18 (35)	0.114
Hyperlipidemia, n (%)	194 (74)	39 (76)	0.716
Smoking, n (%)	167 (64)	24 (47)	0.025
Indications of CAS			
Symptomatic TIA, n (%)	87 (33)	16 (31)	0.799
Symptomatic stroke, n (%)	23 (9)	1 (2)	0.146
Asymptomatic, n (%)	154 (59)	34 (67)	0.293
Previous CEA, n (%)	145 (55)	30 (59)	0.647

CAS, carotid artery stenting; CEA, carotid endarterectomy; CRI, chronic renal insufficiency; TIA, transient ischemic attack.

Table 2
Demographic/Clinical Characteristics and Renal Function Based on Glomerular Filtration Rate

Variable	Normal (≥ 60 mL/min/1.73 m ²)	Moderate/severe CRI (<60 mL/min/1.73 m ²)	p Value
n	196	117	
Hypertension, n (%)	166 (85)	105 (90)	0.205
Coronary artery disease, n (%)	150 (77)	92 (79)	0.668
Congestive heart failure, n (%)	35 (18)	35 (30)	0.013
Diabetes mellitus, n (%)	89 (45)	53 (45)	0.985
Hyperlipidemia, n (%)	144 (73)	89 (76)	0.61
Smoking, n (%)	129 (66)	62 (53)	0.024
Indications of CAS			
Symptomatic TIA, n (%)	64 (33)	39 (33)	0.901
Symptomatic stroke, n (%)	11 (6)	13 (11)	0.077
Asymptomatic, n (%)	122 (62)	66 (56)	0.308
Previous CEA, n (%)	111 (57)	64 (54)	0.739

CAS, carotid artery stenting; CEA, carotid endarterectomy; CRI, chronic renal insufficiency; TIA, transient ischemic attack.

Table 3
Perioperative Complications/Renal Functions Based on Serum Creatinine Levels

Complication	Normal (<1.5 mg/dL)	Moderate CRI (1.5–2.9 mg/dL)	Severe CRI (≥ 3 mg/dL)	p Value
n	262	47	4	
Stroke, n (%)	13 (5)	0	1 (25)	0.056
Myocardial infarction (MI), n (%)	0	1 (2)	0	0.163
Death, n (%)	1 (0.4)	0	0	1
Major adverse events (stroke, MI, death), n (%)	13 (5)	1 (2.1)	1 (25)	0.179
Transient ischemic attacks	3 (1.2)	1 (2.1)	1 (25)	0.056

CRI, chronic renal insufficiency.

Table 4
Perioperative Complications/Renal Functions Based on Glomerular Filtration Rate

Complication	Normal (≥ 60 mL/min/ 1.73 m ²)	Moderate CRI (30-59 mL/min/1.73 m ²)	Severe CRI (<30 mL/min/1.73 m ²)	p Value
n	196	108	9	
Stroke, n (%)	9 (4.6)	4 (3.7)	1 (11.1)	0.44
Myocardial infarction, n (%)	0	1 (0.9)	0	0.374
Death, n (%)	0	1 (0.9)	0	0.374
Major adverse events (stroke, MI, death), n (%)	9 (4.6)	5 (4.6)	1 (11.1)	0.666
Transient ischemic attacks, n (%)	1 (0.5)	3 (2.8)	1 (11.1)	0.029

CRI, chronic renal insufficiency.

Table 5
Perioperative Complications by Preoperative Indication and Normal Renal Function vs Moderate/Severe Chronic Renal Insufficiency Based on Serum Creatinine

Complication	Normal (<1.5 mg/dL) (n = 262)			Moderate/severe CRI (≥ 1.5 mg/dL) (n = 51)		
	n	%		n	%	P value
Stroke	13	5		1	2	0.481
MI	0			1	2	0.163
Death	1	0.4		0	0	1
MAE (stroke, MI, death) in whole series	13	5		2	3.9	1
MAE (125 symptomatic patients)	10/108	9.3		0/17	0	0.355
MAE (188 asymptomatic patients)	3/154	2		2/34	5.9	0.223

CRI, chronic renal insufficiency; MAE, major adverse events; MI, myocardial infarction.

Table 6
Perioperative Complications by Preoperative Indication and Normal Renal Function vs Moderate/Severe Chronic Renal Insufficiency Based on Glomerular Filtration Rate

Complication	Normal (60 mL/min/1.73 m) (n = 196)		Moderate/Severe CRI (<60 mL/min/1.73 m ²) (n = 117)		p Value
	n	%	n	%	
Stroke	9	4.6	5	4.3	0.895
Myocardial infarction	0		1	0.9	0.374
Death	0		1	0.9	0.374
MAE (stroke, MI, death) in whole series	9	4.6	6	5.1	0.830
MAE (125 symptomatic patients)	6/74	8.1	4/51	7.8	1
MAE (188 asymptomatic patients)	3/122	2.5	2/66	3	1

CRI, chronic renal insufficiency; MAE, major adverse events; MI, myocardial infarction.

Table 7

Late Complications Based on Serum Creatinine Levels

Complication	Normal (<1.5 mg/dL) (n = 244)		Moderate/severe CRI (1.5 mg/dL) (n = 43)	
	n	%	n	p Value
Stroke	7	2.9	0	0.5999
Myocardial infarction	8	3.3	4	0.0875
Death	7	2.9	2	0.628
MAE (stroke, MI, death) in whole series	20	8.2	76	0.247
MAE (stroke, MI, death) (118 symptomatic patients)	9/103	8.7	4/15	0.061
MAE (stroke, MI, death) (169 asymptomatic patients)	11/141	7.8	2/28	1

CRI, chronic renal insufficiency; MAE, major adverse events; MI, myocardial infarction.

Table 8

Late Complications Based on Glomerular Filtration Rate

Complication	Normal (≥ 60 mL/min/1.73 m ²) (n = 182)		Moderate/Severe CRI (<60 mL/min/1.73 m ²) (n = 105)	
	n	%	n	%
Stroke	7	3.9	0	0.050
Myocardial infarction	6	3.3	6	5.7
Death	1	0.55	8	7.6
MAE (stroke, MI, death) in whole series	12	6.6	14	13.3
MAE (stroke, MI, death) (118 symptomatic patients)	4/70	5.7	9/48	18.8
MAE (stroke, MI, death) (169 asymptomatic patients)	8/112	7.1	5/57	8.8

CRI, chronic renal insufficiency; MAE, major adverse events; MI, myocardial infarction.

Table 9
Cox Regression Analysis of Early or Late Stroke, Death, or Myocardial Infarction after Carotid Artery Stenting

Effect	Hazard ratio	95% Wald confidence limits	p Value
Univariate			
Creatinine 1.5 mL/dL	1.2	0.5–2.7	0.674
GFR < 60 mL/min/1.73 m ²	1.6	0.9–3.1	0.127
Hypertension	0.7	0.3–1.7	0.456
Diabetes mellitus	1.1	0.6–2.0	0.832
Coronary artery disease	1.5	0.7–3.5	0.306
Congestive heart failure	1.5	0.7–3.1	0.259
Hypercholesterolemia	1	0.5–1.9	0.990
Smoker	0.7	0.4–1.3	0.216
Asymptomatic	0.5	0.3–1	0.035
Previous CEA	0.3	0.1–0.5	0.0002
Multivariate			
Creatinine 1.5 mg/dL	0.95	0.4–2.5	0.918
GFR < 60 mL/min/1.73 m ²	1.6	0.8–3.3	0.222
Asymptomatic	0.6	0.3–1.1	0.095
Previous CEA	0.3	0.15–0.6	0.0006

CEA, carotid endarterectomy; GFR, glomerular filtration rate.