The value of 3D-CT angiographic assessment prior to carotid stenting

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Objective: **Anatomic suitability for carotid artery stenting (CAS) is determined by arteriography, but this has a discrete stroke risk. We evaluated the use of multidetector CT angiography with three-dimensional reconstruction (3D-CTA) as a noninvasive screening tool for prospective CAS patients.**

Methods: **Between 2003 and 2006, 90 CAS procedures were performed by vascular surgeons at our institution. At the discretion of the operating surgeon, 59 of the potential candidates for CAS underwent screening 3D-CTA of the aortic arch and carotid arteries. Results were used in patient selection and then analyzed retrospectively to determine clinical utility.**

Results: **Analysis of 3D-CTA data by the operating surgeon allowed stratification of patients into four groups: (1) appropriate for CAS via femoral approach (n = 37, 63%); (2) appropriate for CAS with transcervical access due to adverse arch anatomy (n = 2, 3%); (3) borderline anatomy for CAS (n = 5, 9%); or (4) not appropriate anatomy for CAS (n = 15, 25%). Group 1 had 100% technical success with one minor stroke. Group 2 had successful transcervical CAS without stroke. Group 3 patients underwent arteriography but CAS was aborted in four out of five cases for the same reason that had been identified by 3D-CTA (internal carotid artery [ICA] tortuosity n = 2, ICA string sign with distal disease n = 2). The one failure in group 3 was the result of a previously placed common carotid stent extending into an already unfavorable aortic arch. Group 4 patients underwent endarterectomy (n = 7) or continued medical management (n = 8) instead of CAS (without arteriography) because of the following reasons, cited alone or in combination: common carotid tandem stenosis n = 5, difficult arch anatomy n = 2, ICA tortuosity n = 2, extreme lesion calcification or length n = 4, ICA string sign or occlusion n = 3, concomitant intracranial disease n = 2, and stenosis overestimated by duplex n = 3. The overall 30-day stroke rate, on an intention to treat basis, for patients that underwent preprocedural 3D-CTA was 2.3% (one major [NIH stroke scale >3] and one minor stroke).**

Conclusions: **In our initial experience, 3D-CTA reconstruction of the aortic arch and carotid arteries significantly influenced the plan for CAS in 37% of patients. Patients with clear anatomic contraindications to CAS can be excluded without the risks of arteriography. 3D-CTA further facilitates the CAS procedure by anticipating potential procedural. The cost-effectiveness and potential impact of this imaging modality on CAS outcomes deserve further study. (J Vasc Surg 2009;49:614-22.)**

Contemporary registry and randomized trials of carotid artery stenting (CAS) with embolic protection report high rates of technical success in the 87% to 99% range.[1] Most of these reports are focused on device development and efficacy and give little guidance for patient selection. The same studies report overall stroke rates of 2% to 8%.[1] In fact, most industry-sponsored registries have reported 30-day stroke rates in excess of 3%, the threshold guideline set by the American Heart Association for carotid endarterectomy (CEA) in asymptomatic patients.[2] Reports from the CREST study lead-in group,[3] registry data,[4,5] the recently published EVA-3S study,[6] and SPACE trials,[7] provide convincing data that the stroke rate associated with CAS may be significantly higher in symptomatic and elderly patients. The explanation for correlations of age and the presence of preprocedural symptoms with CAS morbidity is not known precisely, but authors have demonstrated that advanced age, at least, may be a surrogate for challenging aortic arch anatomy and disease in the access vessels.[8,24,25] In addition, there may be characteristics of the bifurcation lesion itself that may be more dangerous for CAS.[9]

Despite the potential importance of anatomic factors for CAS outcome, our current pre-CAS anatomic assessment is quite limited. Duplex ultrasound provides information only about the region of the carotid bifurcation and conventional arteriography tends to under-represent the atherosclerotic burden of the aortic arch and exposes the patient to a measurable risk of stroke. Also, because arteriography is usually done as the first step of the CAS procedure, it does not allow time for thoughtful patient selection. A more thorough, yet noninvasive pre-CAS anatomic evaluation may help identify patients that should not undergo or are at high-risk for CAS based on characteristics of the aortic arch, common carotid artery (CCA), the bifurcation lesion itself, and of the distal internal carotid artery (ICA). Drawing on our center's experience with three-dimensional (3D) imaging of aortic aneurysms,[10] we

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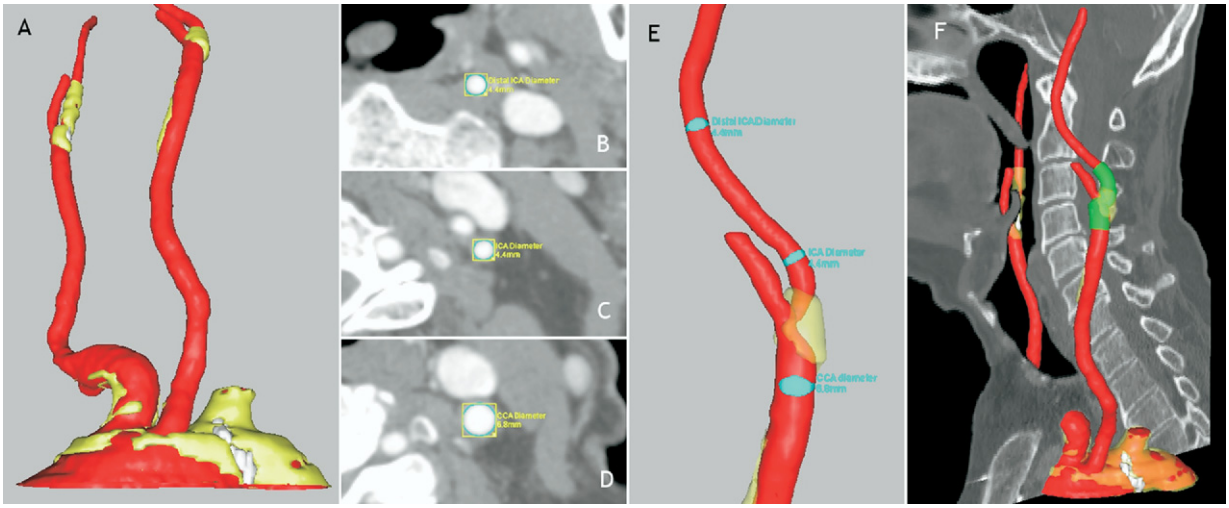

Fig 1. Representative anatomy that would be considered favorable for carotid artery stenting (CAS). Bloodflow is modeled red; atheromatous plaque is yellow; and calcified plaque is white. **A,** Simulated LAO projection of a favorable "type 1" aortic arch. **B-D,** Orthogonal diameter measurements of the common carotid artery (CCA), proximal and distal ICA at sites indicated in (**E**). **E,** Magnified view of a favorable bifurcation lesion with, little calcification or tortuosity. The appropriate gantry angle for best view can be calculated. **F,** Sagital reformat with three-dimensional reconstruction superimposed to illustrate appropriate bony landmarks and to show a simulated tapered carotid stent (*green*).

sought to determine the clinical utility of a similar 3D-CT angiographic analysis as an anatomic screening tool prior to CAS.

METHODS

CAS has been performed by vascular surgeons in our center since December 2000, and our initial experience has been previously reported.[11] We began selective screening of potential CAS patients with 3D-CTA in 2003. The records of all patients being considered for CAS who also underwent 3D-CTA reconstructions of the carotid arteries using Preview software (M2S, Inc., West Lebanon, NH) between 2003 and 2006 were reviewed retrospectively. No industry consideration or funding was provided for the performance of this study. Patients were selected for 3D-CT imaging at the surgeon's discretion without precise criteria, but no attempt was made to select higher risk patients for this screening. The number of patients who underwent Preview 3D reconstruction has increased steadily since 2003, and currently nearly every potential CAS patient is screened in this manner. Analysis of the 3D-CTA data was used in the preprocedure planning for the CAS procedure. Review of these studies, along with clinical risk and duplex ultrasound imaging, was performed by vascular surgeons skilled in CAS techniques. Anatomically unsuitable patients were managed with CEA or medical therapy. Their outcomes were determined by retrospective chart review. Patients who went on to receive carotid stents were prospectively entered into a database. Additionally, the majority of CAS patients are tracked in one of several CAS research protocols or stent registries. Technical success was defined as successful deployment of the embolic protection device (EPD) and stent with $<30\%$ residual angiographic stenosis. The National Institutes of Health Stroke Scale (NIHSS) was used to categorize major (NIHSS score >3) and minor (NIHSS score ≤ 3) strokes. The unprotected use of any angioplasty balloon, guidewire, or stent was recorded. Nonstandard maneuvers, outside the conduct of a routine CAS procedure, were also noted (eg, use of a "buddy-wire" or balloon expandable stent).

All patients were examined by a neurologist before and within 24 hours following the CAS procedure. This analysis was approved by our institutional IRB.

3D-CTA protocol. Contrast-enhanced axial images are obtained to include the ascending and proximal descending aortic arch thru the circle of Willis (Fig 1). The typical CT-angiographic protocol requires a multidetector scanner (16 or higher) to allow continuous acquisition of 1.25 mm thickness slices with 0.6 mm overlap. The typical contrast dose for a CTA including the circle of Willis is 95 cc of Omnipaque 350 or the equivalent. The raw CT data set is transferred electronically to M2S, Inc. (Lebanon, NH) for 3D reconstruction. As with aortic Preview 3D models, length and orthogonal diameter measurements can be performed and are based on the vessel centerline. Multiplanar reformatted images can be viewed on any personal computer. In the model, blood-flow is colored red, soft plaque or atheroma is yellow, and calcium appears white.

Screening considerations. Criteria used to evaluate each patient's suitability for CAS were largely subjective and were not prospectively standardized across different surgeon-interventionalists. Consideration was given to the degree of atherosclerosis and tortuosity present in the aortic arch, ipsilateral CCA, and ICA that would compli-

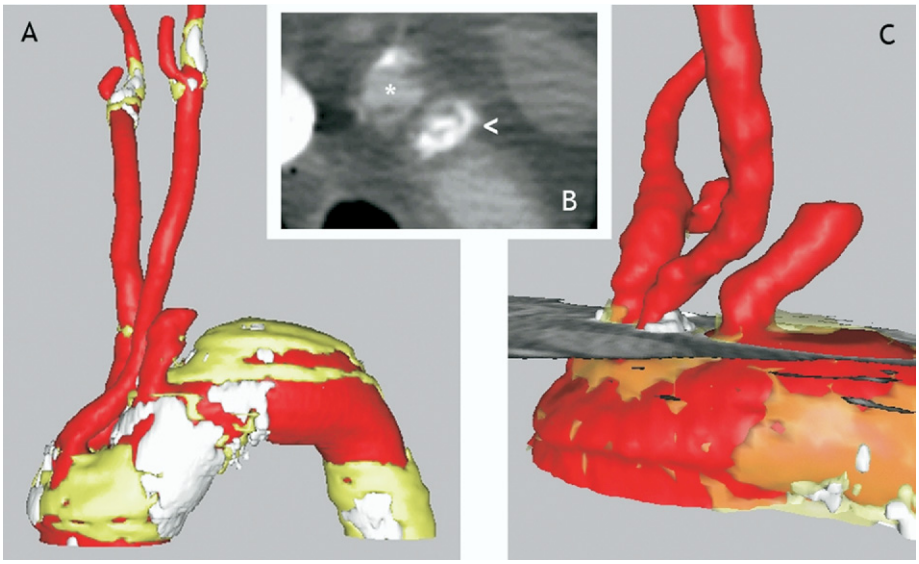

Fig 2. Vessel access problems. **A,** Type III aortic arch; all brachiocephalic vessels emanate from the proximal ascending aorta. This arch configuration will make stable sheath access to the distal common carotid artery (CCA) very difficult or impossible from a groin approach. **B** and **C,** A second aortic arch with a severe CCA origin stenosis. (**B**) is the orthogonal CTA reformatted image at the level of stenosis indicated in (**C**). The asterisk (*) marks the innominate artery and the < indicates the stenotic CCA origin.

cate delivery of the sheath, stent or distal EPD. Examples of such adverse anatomy would include, significant CCA stenoses, short CCA with ECA occlusion, or 180 degree bends in the CCA or ICA. Examples of favorable (type I) and unfavorable (elongated or type III) aortic arch configurations are shown in Figs 1 and 2. Circumferential calcification of the bifurcation lesion or long lesions that would require more than one stent was also viewed unfavorably. The reason(s) cited by the surgeon-interventionalists for CAS denial were ascertained retrospectively from the medical record. Figure 1 illustrates favorable anatomic features of a patient that was approved for CAS using traditional transfemoral access. For those patients who were deemed appropriate candidates for CAS, orthogonal diameter and centerline length measurements were also routinely used to guide stent size and EPD selection. Optimal image intensifier gantry angles were also simulated to help expedite the CAS procedure.

RESULTS

Fifty-nine potential CAS patients were screened with 3D-CTA during the study period. Based on the surgeon's analysis of the 3D-CTA reconstruction, 37 patients (63%) were approved for conventional CAS using femoral access. Concurrently, an additional 51 patients underwent attempted CAS without screening. Thus, there were 88 consecutive CAS patients, who underwent the procedure from a femoral approach, over a 3-year period, available for retrospective review.

Patient characteristics are listed in Table I. Screened patients were older and had lower incidences of coronary artery disease, renal insufficiency, and statin use. The proportion of patients with symptomatic carotid stenosis and restenotic lesions was the same in both groups.

Table I. Patient characteristics

	CAS with 3D-CTA (n = 44)	*CAS without 3D-CTA (n = 52)*	P *value*
Mean age (y)	74 ± 8	70 ± 10	.05
Male gender	77%	67%	.25
Diabetic	26%	43%	.08
Coronary artery Dz	63%	84%	.02
Hypertension		84%	.7
Creatinine >1.8	3%	19%	.02
Tobacco	71%	77%	.4
Statin	55%	76%	.03
Asymptomatic	64%	61%	.9
Restenosis	21%	25%	.61

CAS, Carotid artery stenting.

Twenty-two of the 59 screened patients (37%) were not considered to be good candidates for CAS based on anatomic characteristics, and 15 of these (25%) were considered altogether inappropriate for CAS. These patients were denied CAS for specific anatomic reasons shown in Table II and representative examples of each are shown in Figs 2-7. Some patients had more than one adverse anatomic criterion. Of the 15 patients who were denied CAS, seven went on to have CEA and eight were managed medically. There have been no strokes among these patients.

There were five patients (9%) whose anatomy was characterized as borderline for CAS. A decision was made to

Table II. Anatomic criteria

Anatomic criteria	*n*	*Problem for CAS*	*Illustration*
Vessel access problems			Fig 2
Difficult arch	4	Type III arch configuration; Severe arch atherosclerosis	A
Tandem CCA stenosis	3	Potential for failed/unsafe access or distal embolization	B and C
Lesion characteristics			Figs 3 and 4
Near-occlusions	5	Lesion too stenotic to be crossed by EPD without unprotected predilatation	Fig 3
Circumferential lesion calcification	4	Higher risk for atheroembolism or suboptimal result (residual stenosis)	Fig 4
CTA lesion less stenotic than duplex	3	Lesion does not meet criteria for intervention	
Distal ICA/intracranial			Figs 5, 6, and 7
True carotid "string sign"	2	High risk of occlusion due to low flow; distal ICA too small for EPD	Fig 5
Distal ICA tortuosity	2	Unable to safely deploy EPD	Fig 6
Severe intracranial disease	2	Potential for embolization from wire manipulation	Fig 7

CAS, Carotid artery stenting; *CCA,* common carotid artery; *CTA,* CT angiography; *EPD,* embolic protection device; *ICA,* internal carotid artery.

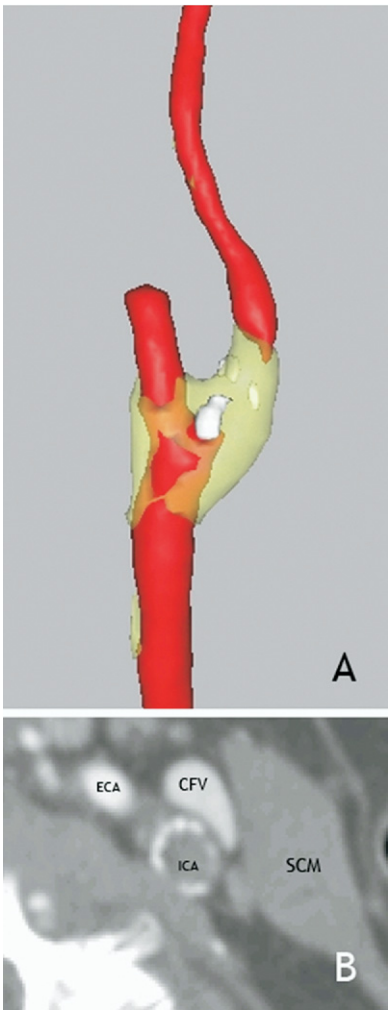

Fig 3. Near occlusions. **A,** Magnified view of the carotid bifurcation with the soft plaque (*yellow*) made transparent. The flow channel (*red*) is not detectable thru the bifurcation stenosis. **B,** Orthogonal reformat thru the mid portion of the bifurcation stenosis confirms the lack of visible contrast within the calcified rim of the carotid bulb. *ECA,* External carotid artery; *ICA,* internal carotid artery; *SCM,* sternocleidomastoid muscle; *CFV,* common facial vein.

proceed with diagnostic angiography and possible carotid stenting, anticipating that there may be some difficulty encountered. Four of these patients were aborted after the diagnostic arteriogram, and one was attempted but failed. In all five cases, the reason that the CAS was not performed corresponded to the anatomic feature identified by the 3D-CTA. Specifically, two patients had near occlusive lesions that were thought too stenotic to allow passage of the EPD without unprotected predilitation. One patient had a shelf-like lesion of the distal CCA that, combined with the sheath position, prevented even wire access of the ICA despite several attempts. The remaining two patients had critical tortuosity problems and were aborted without attempt at CAS: one whose left CCA originated deep within the ascending aortic arch (severe type III arch anatomy) and the other who had an acute angle in the ICA immediately beyond the stenosis that would have been accentuated by any stent, creating the potential for an ICA kink.

Two patients comprise the final group whose plan was altered by screening 3D-CTA. These had acceptable anatomy at the bifurcation and distal ICA but the aortic arch configuration and atherosclerotic disease burden in the arch (Fig 2) would have made a femoral approach dangerous. Therefore, the approach for CAS was hybridized with an open cervical access under local anesthesia. Both patients treated this way had no complications.

There was one major (NIHSS >3) and one minor stroke in CAS patients screened with 3D-CTA; one major and two minor strokes occurred in the unscreened CAS group. These differences are not statistically significant. There was no difference in technical success between the group approved by screening (100%) and unscreened (98%) groups (P = ns). The frequency of unprotected or nonstandard maneuvers however was higher in the nonscreened group (n = 6, 12%) vs the screened group (n = 2, 5%) though this difference was not significant (P = 0.3). Most commonly, these maneuvers consisted of unprotected predilitation to deliver the EPD, unprotected stenting (because there was not enough room in the distal ICA for the protection device), or the use of a buddy wire to straighten tortuous anatomy. Additionally, one balloon

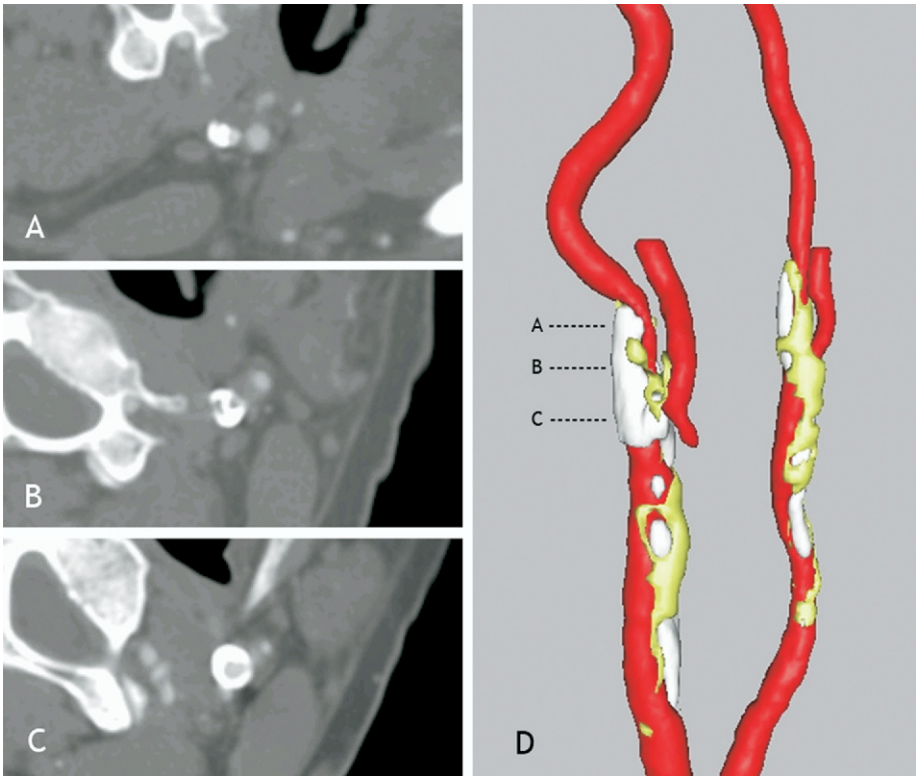

Fig 4. Extreme lesion calcification. **A-C,** Orthogonal reformatted CT images at proximal **(A)**, mid **(B)**, and distal **(C)** portions of the bifurcation plaque seen at the right in image **(D)**. Calcification is nearly circumferential at each level of the lesion.

expandable stent was used inside of the self-expanding carotid stent to expand a resistant, heavily calcified lesion.

DISCUSSION

The technical aspects of carotid endarterectomy are influenced almost exclusively by the level of the carotid bifurcation and by the quality of the proximal and distal endpoints of the endarterectomy site. The three-dimensional vascular anatomy at the level of the aortic arch, common carotid and distal ICA play a much larger role in the technical success and clinical outcome of the CAS procedure than they do for CEA. Experienced interventionalists might argue that there are very few anatomic situations that would make CAS technically impossible. This may be true. However, clearly suboptimal anatomy encountered during the "diagnostic" arteriogram portion of the CAS procedure, as our data suggests, may tempt even conservative operators to persist with prolonged catheter manipulation in the aortic arch or with unprotected maneuvers that will place the patient at increased stroke risk. With this preliminary study, we propose 3D-CTA as a universally available, noninvasive way to screen out the worst candidates for a procedure that has become increasingly scrutinized and criticized, because of its relatively high procedural stroke rate. This could be especially important for less experienced operators, and may allow for better patient selection and planning even for experienced interventionalists.

Some useful information can be gleaned from axial CTA images, but tortuosity and lengths are much better evaluated with some type of 3D rendering. At our institution, we are used to using the M2S Preview software for this purpose and value its portability using a standard personal computer and superior functionality relative to CT-workstation-based reformatted images. The cost for M2S reconstruction is CMS-reimbursable for use in preoperative planning. In general, we prefer CTA over MRA because of the better visualization of vessel calcification with CTA and because of its lower cost. The purpose of this article, however, is not to advocate this particular technology so much as it is to bring to light some of the potential benefits that a more thorough anatomic screening can bring to the CAS procedure.

The accuracy of 3D-CTA reconstructions seems quite good in our preliminary experience with this technique. Based on the five patients who underwent diagnostic arteriography despite anatomic concerns raised by the 3D-CTA, there was good correlation between the two studies. In each case, the problematic arteriographic feature that precluded CAS was correctly anticipated by the 3D-CTA. Like it does for the evaluation of endovascular aneurysm

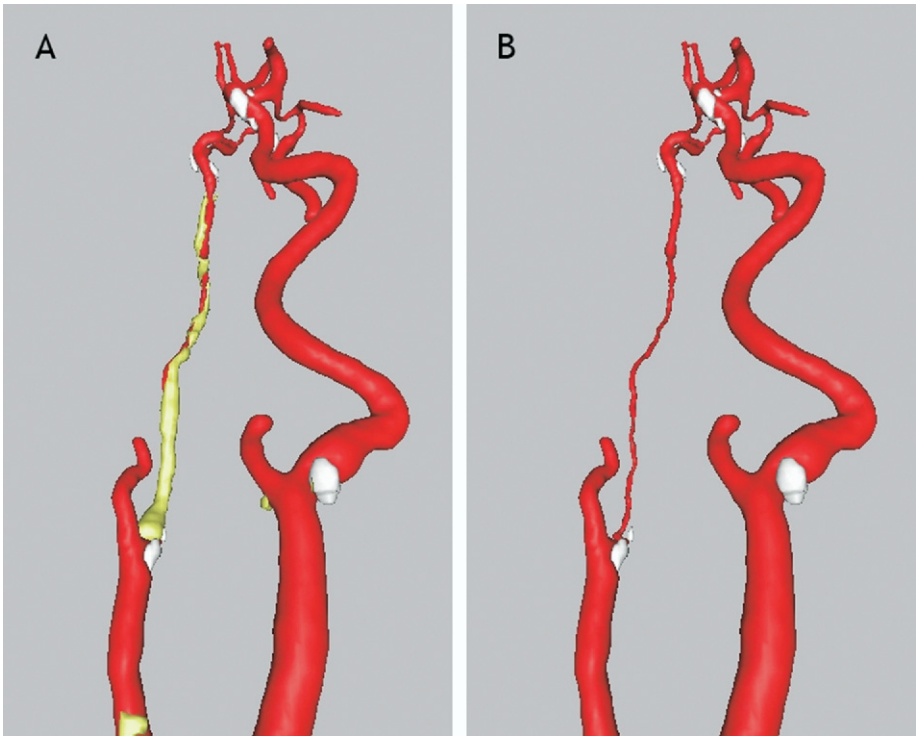

Fig 5. Carotid string sign. Both images are of the same patient. The noncalcified plaque (*yellow*) has been removed in (**B**) to demonstrate the diminutive flow channel as it extends all the way to the base of the skull.

repair candidates, Preview integrates the evaluation of calcium, noncalcified atheroma, and tortuosity into one easily interpretable, interactive model that is superior to two-dimensional (2D) angiography and can be viewed on any personal computer. We have found that this 3D perspective is much easier appreciated, especially by less experienced operators and trainees.

In this study, inappropriate anatomy of the carotid bifurcation was the most commonly cited reason for CAS denial (n = 12) and contributed to the abandonment (n = 2) or failure (n = 1) of CAS in three of the five patients who were considered borderline or suboptimal candidates. Careful evaluation of the bifurcation lesion itself is important because most of the embolic events associated with CAS occur from the bifurcation during balloon predilitation, and stent placement.[12] CTA provided considerably more information about the bifurcation than duplex ultrasound typically does, especially regarding the extent of lesion calcification. Unlike complicated B-mode duplex ultrasound analysis used by some to evaluate embolic potential during CAS,[9,13,14] CTA is user independent and readily available. Further study is required with lager patient numbers to determine exactly which 3D-CTA features correlate with atheroembolic potential.

Atheroembolization does not only occur during manipulation of the bifurcation itself. Transcranial duplex monitoring has demonstrated atheroembolic events at all stages of the CAS procedure.[15,16] DWI-MR data suggest that there is a significant amount of atheroembolic events that occur even with filter-protected CAS.[17-20] These events can occur in hemispheres, both ipsilateral and contralateral to the treated bifurcation lesion which implicates the aortic arch as the source. Furthermore, Hammer et al[21] showed that the rate of such events was seven times higher in a subset of their patients who had technically challenging CCA-arch configurations on the basis of arch to CCA angulation or proximal CCA tortuosity. Although many of these events are clinically silent, periprocedural stroke occurred only in patients with new DWIs. These events would seem avoidable by limiting unnecessary cannulation of the contralateral CCA or by avoiding catheter manipulation in the aortic arch entirely. In fact, one small study using cervical access and flow reversal was able to demonstrate no embolic events by transcranial Doppler.[22] These studies suggest that unfavorably configured or diseased aortic arches are more likely to cause atheroembolization and should be avoided if possible.

Anatomic concerns in the intracranial circulation may also be important but there is little published information as it relates to the CAS procedure. Gay et al,[23] using the Eurocast CAS registry, suggested that an incomplete circle of Willis (COW) significantly increased the 30-day transient ischemic attack (TIA)/stroke rate. Only 19 of the patients screened in our study had CTA that included the intracranial circulation but two of these patients were denied CAS, in part because of extensive intracranial disease.

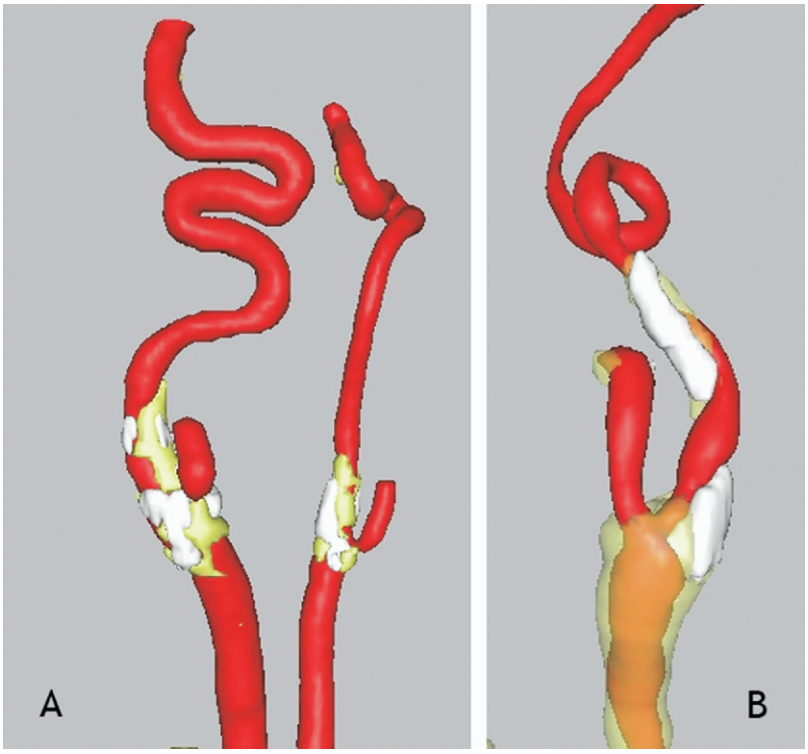

Fig 6. Severe ICA tortuosity. **A,** Multiple 180 degree bends in the distal ICA will prevent safe deployment of a distal embolic protection device (EPD). **B,** A complete ICA loop will also complicate placement of the EPD. Placing a stent close to such a tortuous segment will also potentially result in an exacerbation of the tortuosity or create a kink.

We did not, however, formally evaluate the "completeness" of the COW as part of this study.

Beyond patient selection, preprocedural 3D-CTA helps facilitate procedure planning, identify potential pitfalls, and select the correct equipment for each patient. For example, the optimal image intensifier gantry angle for the carotid bifurcation is quite variable from patient to patient. This can be easily determined from the 3D-CTA to save time, contrast, radiation exposure, and frustration. The correct stent length, diameter, and shape (tapered or straight) can be determined using centerline length and orthogonal diameter measurements, respectively. There are now several EPD varieties available such as distal occlusion balloon, filters, and flow reversal devices. Across the different subtypes and even within each subtype, there are relative strengths and weaknesses (crossing profile, flexibility, wire choices etc.) that may be amplified by a patient's specific anatomy. We did not collect data prospectively as to the type and size of EPD or size stent that was selected preprocedurally based on the 3D-CTA to allow an analysis compared with the actual devices used. Despite this, we believe that planning the procedure with 3D-CTA also allows preselection of the EPD type and size with accuracy. This will be the subject of future study to confirm this impression. All of these factors are especially important for those just learning the CAS procedure. We believe that such a pre-CAS evaluation can minimize the amount of on-the-fly interpretation and decision making that is required and allow the operator to be more self-assured and to focus on the technical aspects of the procedure. For many of the same reasons, we have also found this to be a very beneficial training tool for our own vascular surgery fellows.

This study is limited in several important ways. Retrospective analysis and the subjective criteria by which patients were screened limit the ability to draw any firm conclusions. Any anatomic screening for CAS, by its nature, is subjective because there are no uniformly accepted anatomic risk factors for CAS. In future study, we hope to identify and quantify which anatomic features are most important and thereby standardize this anatomic screening tool. Our study was not powered to detect any difference in stroke rates or technical success between the screened and unscreened groups. The technical success rates are so high and neurological event rates are so low that many more patients would need to be included to show any potential difference. It could be argued that our good results in both groups demonstrate a lack of benefit from 3D-CTA prescreening. However, our subjective experience with this technique has convinced us of the value of screening patients for CAS and temporally separating this screening and preprocedure planning from the CAS procedure itself. This separation may prevent the urge to persist with suboptimal anatomy and, thru better planning, streamline the proce-

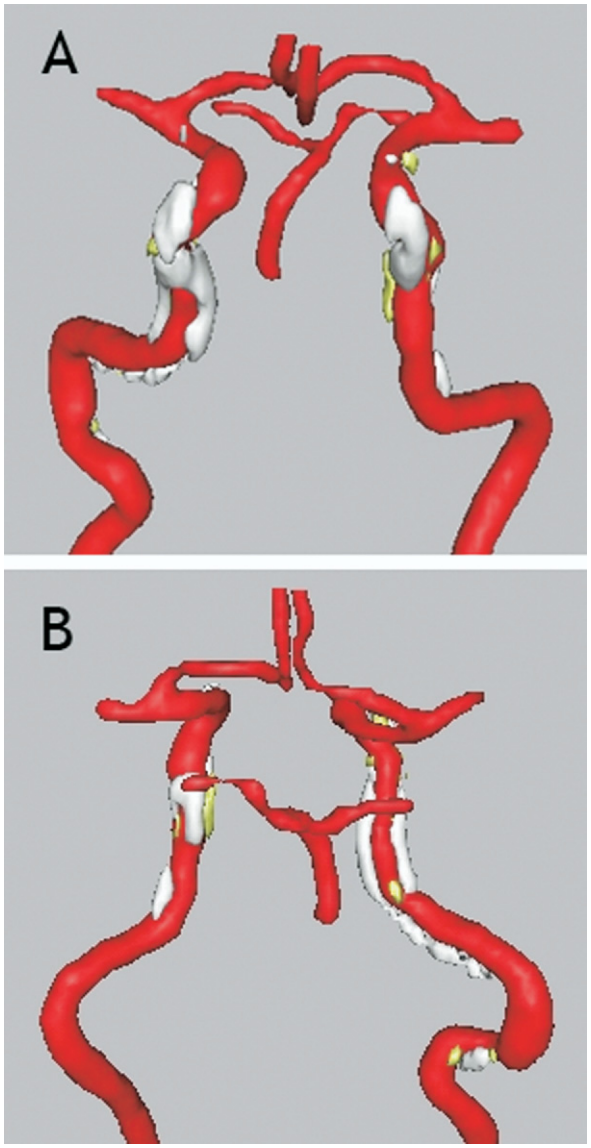

Fig 7. Severe intracranial disease. 3D-CTA reconstruction of the intracranial circulation makes evaluation of the intracranial ICA that may be instrumented by guidewires or by distal embolic protection device (EPD) devices. Further evaluation of the collaterals from the contralateral side or posterior circulation is provided by evaluation of the circle of Willis. Anterior **(A)** and posterior **(B)** views show heavy disease of the carotid siphon and absent posterior communicating arteries in this patient.

dure. Our approach is conservative and may be better described as screening to find the best candidates for CAS since we have eliminated a relatively high number of patients. As surgeons, we have the ability to be selective and to select the best treatment option, medical surgical or interventional for an individual patient. We believe based on this preliminary experience that continued study is warranted to determine the impact of this screening tool on stroke rate and to examine its cost effectiveness.

AUTHOR CONTRIBUTIONS

Conception and design: MW, RP, BN, MF
Analysis and interpretation: MW, RP, JC
Data collection: MW, RP, BN
Writing the article: MW
Critical revision of the article: MW, RP, JC, MF, BN
Final approval of the article: MW, RP, JC, MF, BN
Statistical analysis: MW, RP
Obtained funding: Not applicable
Overall responsibility: MW

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