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Comparison of dual-source CT angiography and MR angiography in preoperative evaluation of intra- and extracranial vessels: a pilot study

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Abstract Besides the assessment of carotid artery stenosis, evaluation of the vascular anatomy and lesions within both the extra- and intracranial arteries is crucial for proper clinical evaluation, treatment choice and planning. The purpose of our study was to evaluate the potential of dual-source CTA and 3T-MRA. In 16 symptomatic CAS patients, contrast-enhanced DSCT and 3T-MRA examinations were performed. For DSCT a dual-energy protocol with a 64×0.6-mm collimation was applied. In 3T-MRA intracranial high-resolution unenhanced TOF and extracranial contrast-enhanced MRA were performed. All examinations were analyzed for relevant morphologic and pathologic features or anomalies, and a total of 624 vessel segments were scored. All examinations were of diagnostic image quality with good to excellent vessel visibility. Almost all intracranial arteries were significantly better visualized by MRA compared to CTA (five of six vessels, $p<0.05$). DSCT however allowed for further morphological carotid stenosis description, especially with respect to calcification. Although MRA proved to be superior in visualization of smaller intracranial arteries, all pre-interventionally relevant information could be perceived from DSCT. DSCT and MRA may both be regarded as a reliable, fast, pre-interventional imaging investigation in patients with carotid artery stenosis.

Keywords Carotid artery · CT angiography · MR angiography · Carotid stenosis · Image quality

Introduction

Atherosclerosis of the carotid arteries is a major cause of stroke and transient ischemic attack [1, 2]. Stroke is fatal in about 40% of cases, and surviving individuals often suffer from severe disabilities that require costly clinical care [2, 3]. Often atherothromboembolism from a focal atherosclerotic plaque at the carotid bifurcation is the cause of stroke and carotid stenosis and is present in about 25% of all strokes [4, 5].

Imaging investigations for diagnosis of significant carotid artery stenosis include digital subtraction angiography (DSA), MR angiography (MRA), Doppler ultrasonography (US) and also multi-detector row CT angiography (CTA) [6–16]. DSA is still considered the gold standard for evaluation of carotid artery stenosis, but the risk of neurological complications is estimated to be between 0.05 to 0.5% [17, 18]. Ultrasound is not capable of imaging all vessels that are relevant for the brain's blood supply. Therefore, in clinical practice non-invasive imaging techniques such as MRA or CTA are used for diagnosis and pretherapeutical planning [7, 19–23]. With the advent of higher field strengths (3 T), MRA has evolved as a powerful tool for imaging of the extracranial and intracranial vessels [19–25].

However, contrast-enhanced MRA still suffers with problems of movement and susceptibility artifact around the aortic arch, which can only party be avoided by right-sided contrast injections. With improved spatial and temporal resolution in CT and the introduction of dual-source CT (DSCT), CTA also has evolved considerably over the last years to become an accurate and reliable tool to assess the degree of carotid artery stenosis [26–33]. Clinical studies have shown that the degree of stenosis, the clinical presentation of the patient and how quickly the patient is imaged are the most important determining factors whether or not a conservative management or an invasive treatment is necessary. Concerning invasive treatments, there is a constant debate as to whether percutaneous balloon angioplasty with subsequent stent placement or surgical endarterectomy is the method of choice. Irrespective of this discussion, before each therapeutic approach, detailed knowledge of the anatomy, possible variations and the vessel pathology of all major cerebral arteries is important and may become even more crucial in the future [34, 35]. Moreover, in depth evaluation of the stenotic vessel with respect to its configuration and the plaque composition may help to improve patient outcome [36]. Still, most previously published studies focused mainly on the evaluation of the carotid vessel itself.

The aim of the present study was to compare 3T-MRA and dual-source CT (DSCT) angiography in preoperative evaluation of intra- and extracranial vessel anatomy and pathology in patients with symptomatic carotid artery stenosis before surgical carotid endartherectomy with respect to the visualization of both the diseased vessel segment and also the other vessels that may play a role in the treatment decision.

Material and methods

Patient population

Sixteen clinically symptomatic patients (2 female, 14 male, mean age 67.2 ± 12.3) with regular kidney function and suspected stenosis of the carotid artery and lumen reduction of at least 50% on duplex were prospectively enrolled in this study [37]. Ethical approval was given by the local ethics committee, and all patients gave informed consent for all procedures. Within a timeframe of 3 days both DSCT and 3T-MRA were successfully completed in all patients.

DSCT was performed using a SOMATOM Definition CT system (Siemens Medical Solutions, Forchheim, Germany). A dual-energy protocol with tube settings of 140 kV/55 mAs for tube A and 80 kV/230 mAs for tube B was applied. A collimation of $2\times2\times32\times0.6$ mm with z-sharp technology, a pitch of 0.65 and a rotation time of 0.33 s were used. For optimal bolus timing the test bolus technique with 20 ml of iodine-containing contrast media

(Ultravist 300, Bayer-Schering, Berlin, Germany) injected into a right-sided cubital vein at a flow rate of 6.1 ml/s followed by a 40-ml saline chaser was performed before the actual CT data acquisition. The optimal delay was then individually determined from the time enhancement curve. For the main CT data acquisition, 123 ml of contrast medium was applied through an intravenous 18-gauge i.v. line followed by a saline chaser of 40 ml, both injected with the identical flow rate of 6.1 ml/s. CT data were acquired in a caudo-cranial direction from the aortic arch to the top of the skull. Images were reconstructed with 0.6-mm slice thickness and an increment of 0.4 mm applying a smooth convolution kernel. In addition, coronal and sagittal multiplanar reformations and maximum intensity projections were reconstructed.

MRA angiography

All MR examinations were performed at a 3T- MR scanner (Achieva, Philips Medical Systems, Best, The Netherlands). Patients were examined in a supine position using an eight-channel head-neck coil. Followed by a survey, anatomical FLAIR and the following non-enhanced image sequences were acquired: fluid-attenuated inversion recovery (FLAIR) sequences (TR/TE/FA/TI: 11,000/125/90/2,800) covering the whole head with 5-mm sections; diffusion-weighted sequences (DWI) (TR/TE/FA: 1,920,877/55/90) and un-enhanced time-of-flight angiographies (TR/TE/FA) (25/3.45/20). The latter was performed with a matrix of $1,024 \times 1,024$ and a FOV of 200×200 mm^2. Slice thickness was 1 mm resulting in an voxel size of $0.2 \times 0.2 \times 0.2$.

Contrast-enhanced (CE) MRA was performed using a bolus tracking method using 20 ml of gadolinium (Multihance, Bracco) injected at 3 ml/s. Parameters for the CE sequence were as follows: TR 4.1 ms; TE 1.15 ms, flip angle 40 matrix 352×351, slice thickness 60 mm and voxel size 0.57/0.57/0.80 mm^3. Images were rendered as MIPs in 16 projections separately for both carotid arteries.

Image analysis

Before the study two board-certified radiologists set up a comprehensive scoring sheet for evaluation of vessel anatomy and disease within all major cerebral extra- and intracranial arteries that might potentially influence further diagnostic workup of the patient, but also the choice of treatment (Table 1). Tortuosity or elongation of a vessel was defined as a deviance from a straight vessel course with at least two curves with an angulation of less than 135° (given 180° as a straight course and 90° as a rectangular kink).

Atherosclerotic plaques were visually classified into soft, calcified or mixed plaques. All CTA and MRA examinations were independently analyzed by these two radiologists, and inter-observer agreement between all

Table 1 Scoring sheet for evaluation of vessel anatomy and pathology of extra- and intracranial arteries that was applied for all 16 patients in both modalities (CTA and MRA)

Vessel	Sides	Segments per vessel	No.	Criteria evaluated
Stenosis of internal carotid artery (ICA)	2	1	32	Yes/no, >70% following NASCET criteria
Stenosis geometry	2	1	32	Concentric, eccentric, obstruction
Plaque composition (CTA only)	2	1	32	Soft, calcified, mixed
Adhesive thrombus at stenosis	2	1	32	Yes/no
Elongation of internal carotid artery	2	1	32	Yes/no
Post-stenotic caliber of ICA	2	1	32	Normal, dilated, reduced, obstructed
Stenosis of proximal vertebral artery	2	1	32	Yes/no
Additional intracranial stenoses				Yes/no, location
Vessel abnormalities				Common trunks, duplications, fenestrations, anomalous collaterals, etc.
Brachiocephalic trunk	1	1	16	Visibility on 4-point scale*
Subclavian arteries	2	1	32	Visibility on 4-point scale*
Common carotid arteries	2	1	32	Visibility on 4-point scale*
Internal carotid arteries	2	3	96	Visibility on 4-point scale*
Vertebral arteries	2	3	96	Visibility on 4-point scale*
Basilar artery	1	1	16	Visibility on 4-point scale*
Anterior cerebral artery	2	1	32	Visibility on 4-point scale*
Middle cerebral artery	2	1	32	Visibility on 4-point scale*
Posterior cerebral artery	2	1	32	Visibility on 4-point scale*
Anterior communicating artery	1	1	16	Visibility on 4-point scale*
Posterior communicating artery	2	1	32	Visibility on 4-point scale*
Total			**624**	

*See Table 2

scoring values was determined. The same radiologists also performed the consensus reading of all CT and MRI examinations. Evaluation was performed on a dedicated workstation with certified monitors and lightning. In order to exclude a recall bias a time delay of 2 months was ensured between the readings of the two investigations in each patient. Vessel visibility was evaluated using a 4-point scale with respect to the anatomic depiction, vessel edges and occurrence of artifacts (Table 2).

Table 2 Four-point scoring scale for vessel visibility

Score	Anatomical depiction	Vessel edges	Artifacts
1	Distinct anatomic detail, high degree of vascular opacification	Very sharp	None
2	Anatomic detail clear, most images high degree of enhancement	Sharp	Mild to moderate
3	Obscured anatomic detail, enhancement not sufficient for diagnosis	Blurred	Extensive
4	Not visible		

Statistical analysis

The characteristics of the anatomy and disease demonstrated were compared descriptively. Vessel visibility scores were analyzed applying paired samples t-tests between the two imaging investigations. P-values <0.05 were considered as statistically significant. All statistics were performed using MedCalc version 8.1.1.0 (MedCalc Software™, Mariakerke, Belgium).

Results

The CT and MRA examinations were successfully completed in all patients without the occurrence of any complications. All examinations were rated diagnostic, and there was no compromising venous overlay in CTA or MRA. The average duration for DSCT data acquisition was 10.4 ± 1.6 s (bolus timing excluded) with an average $CTDI_{vol}$ of 10.2 ± 0.8 mGy, whereas the time for MRA data acquisition was approximately 20 min.

Concerning the degree of stenosis, of a total of 32 carotid arteries, 27 were consistently evaluated with both imaging

investigations showing a lumen narrowing ≥70%. The remaining five carotid arteries did not show any significant stenosis in either imaging investigation. Stenosis geometry (eccentric, concentric or occluded) was consistently rated in 21 of these 27 arteries with 16 eccentric stenoses, 4 concentric stenoses and 1 occlusion). In six lesions stenosis geometry differed with respect to being eccentric or concentric with CTA calling two of these lesions eccentric, while MRA revealed eccentric lesions in the other four vessels. Concerning plaque characterization, MRA using the employed routine techniques did not reveal additional information, whereas CTA was capable of rating the 27 lesions as being soft (n=3), calcified (n=5) or of a mixed type (n=19) (Fig. 1); a wall adherent thrombus was not detected by either investigation.

When evaluating the elongation of the common carotid artery, there was a 100% consensus between CTA and MRA, with 2 CCAs being rated as elongated and 30 being rated as non-elongated. In seven vessels a small post-stenotic caliber of the vessel was consistently noted, one artery was occluded, and the remaining 24 vessels were of normal size. Relevant stenosis of the proximal vertebral artery was consistently detected in eight vessels; seven were uniformly rated as patent. In eight additional vessels, however, MRA showed signs of significant stenosis, whereas CTA showed suspicious lesions in yet two other vessels. In two MRA examinations and in one CTA scan, however, the image quality at the origin of the supraaortic vessels was rated non-diagnostic (see evaluation of vessel visibility below).

Consistently both imaging investigations detected a total of three additional intracranial stenoses (>70% lumen narrowing) in two patients in the carotid syphon (two lesions) and in the basilary artery (one lesion).

Several anomalies were also concordantly diagnosed by both investigations: one bicarotid trunk, one direct origin of the left vertebral artery from the aortic arch, one ophthalmic collateral and one doubled middle cerebral artery (Fig. 2). MRA in addition detected one very rare case of a fenestrated basilar artery that initially was not detected by CTA (Fig. 3). No lusoric artery was noted in any of our patients.

With respect to vessel visibility, the vessels listed in Table 1 were evaluated. A total of 624 vessels or vessel segments were scored by both investigations; the results are given in Table 3. CTA and MRA did not reveal any statistically significant difference with respect to visibility of extracranial arteries. MRA, however, revealed better vessel visibility for almost all intracranial arteries; especially small arteries like the posterior communicating artery were much more visible and more frequently detected by MRA (Fig. 4).

Discussion

Different imaging investigations such as ultrasound, CT, MR and conventional invasive digital subtraction angiography are established for assessment of the extra- and intracranial arteries. Several clinical conditions require detailed information on the arterial vessel course and blood supply to allow for a correct diagnosis and choice of appropriate therapeutic procedure. US has emerged as the first-line imaging investigation, especially in the case of suspected stenotic disease of the internal carotid artery at

Fig. 1 Three sample images to demonstrate different types of plaque composition that could be discriminated by CTA: soft (a), calcified (b) and mixed (c) plaque (arrows)
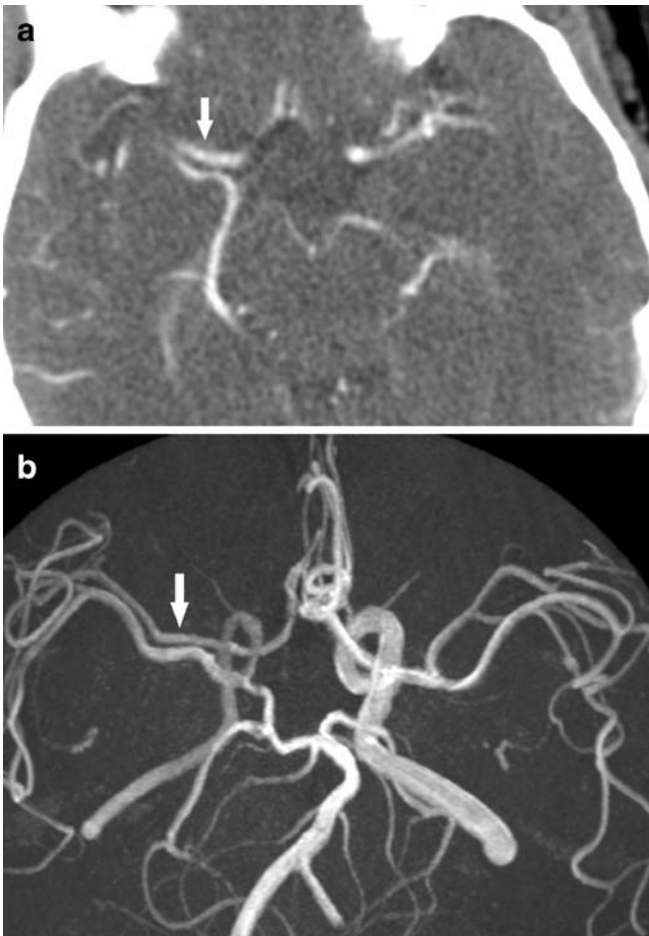
Fig. 2 Axial CTA (a) and maximum intensity projection MRA (b) images of a 53-year-old woman presenting with doubled right-sided middle cerebral artery (arrows)

stenoses that may very well be accessible for endovascular procedures but not for surgical ones or intracranial stenoses that may lead to a change in the choice of treatment. In almost every patient additional information with respect to vessel course, carotid stenosis morphology, additional carotid stenoses and presence or absence of intracranial collaterals was acquired in our study. Intracranial variations were better depicted by MRA—however, those who remained undetected by CTA were of no clinical relevance (such as non-fusions of the basilar artery or very small anterior or posterior communicating arteries) and had no further impact on choices for treatment planning.

With respect to carotid stenosis morphology and plaque composition, DSCT proved to be superior to MRA in our study. This is not surprising, however, as CT is also capable of visualizing the vessel wall and especially of showing calcifications within the atherosclerotic plaque. As the latter is important information for planning the intervention or surgery, a substantial amount of calcification will hamper the diagnostic accuracy of CTA because of the well-known blooming effect of these dense lesions. Plaque
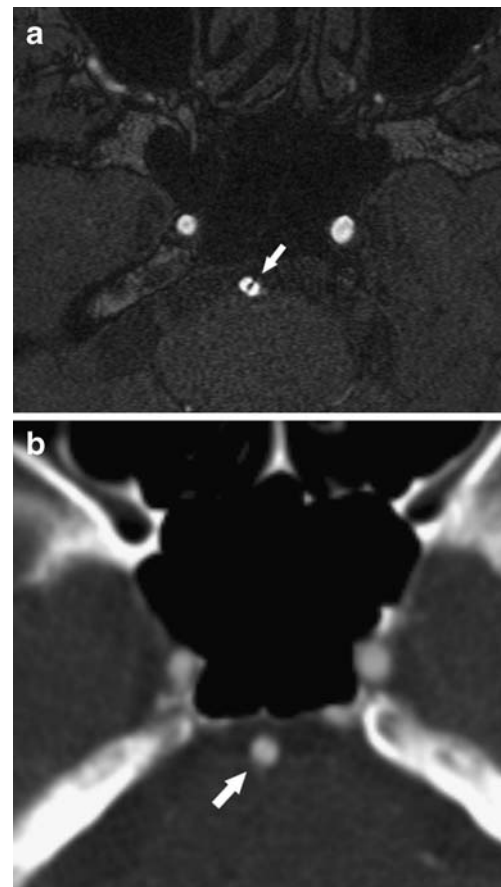

Fig. 3 Axial MR image (a) from the time-of-flight sequence clearly showing a fenestrated basilar artery (arrow) in a 64-year-old man. This finding was retrospectively only faintly visible in CTA (arrow in b)

the extracranial bifurcation. MRA, especially with introduction of high-field and parallel imaging, became the substitute for DSA in most cases for definite diagnosis and preoperative or pre-interventional planning. CTA has been shown to be also capable of correctly measuring the degree of carotid stenosis [28, 30].

Little attention, however, has been paid to the capability of CTA and MRA in imaging arterial vessel disease and vascular abnormalities aside from the carotid artery; moreover, no previous study compared the vessel visibility of all major extra- and intracranial arteries using 3T-MRA and DSCT in patients with suspected stenotic carotid disease. This information, however, has clinical relevance in a variety of case scenarios: elongation of CCA, which is difficult to access using stents; "isolated ICA" (without a contralateral first segment of the anterior cerebral artery, or anterior communicating artery and missing posterior communicating artery) with a potentially more devastating clinical course when major vessel occlusion occurs; anatomical variations important for surgical or endovascular access (height of bifurcation, etc.), associated tandem

Table 3 Vessel visibility in CTA nd MRA based on a 4-point scoring scale (see Table 2)

	Mean score CTA	SD	Mean score MRA	SD	p-value
Brachiocephalic trunk	1.7	0.8	1.9	1	0.432
Subclavian arteries	1.6	0.7	1.9	1	0.174
Common carotid arteries	1.3	0.5	1.4	0.4	0.153
Internal carotid arteries	1.3	0.5	1.3	0.6	0.724
Vertebral arteries	1.6	0.8	1.7	0.8	0.158
Basilar artery	1.3	0.4	1.1	0.2	0.083
Anterior cerebral artery	1.8	0.7	1.6	0.6	0.026*
Middle cerebral artery	1.5	0.4	1.2	0.4	0.015*
Posterior cerebral artery	1.7	0.6	1.2	0.3	<0.001*
Anterior communicating artery	2.5	0.6	1.9	0.7	0.034*
Posterior communicating artery	3.6§	0.8	2.7#	1.1	<0.0001*

*Statistically significant, §: 9 detected, #: 21 detected

imaging with MRI will be helpful in the future, but at present is still experimental and very time consuming. For a rapid treatment decision as to whether a densely calcified eccentric high-grade stenosis is present, CTA appears to be the better alternative. Although sophisticated CTA software tools for calcium removal have not yet proved to be very

Fig. 4 Maximum intensity projection MRA image (a) of a 50-year-old man that nicely shows a left-sided posterior communicating artery (arrow). In CTA (b) this vessel was only vaguely visible (arrow)

efficient [38], the full information from dual-energy CTA may overcome this limitation and help even further to discriminate other plaque components, as has just been recently shown [39]. With dedicated MRI sequences applied, further analysis of plaque morphology also is possible [7, 11, 40, 41]. As we did not want to increase the overall imaging time beyond a degree that is practicable in an everyday clinical setting, these specially focused MRI sequences were not applied in our study.

While analyzing the CT- and MRI examinations, it again becomes obvious that a combination of several post-processing techniques is the key to efficient and comprehensive image interpretation. In CTA the focus was placed on axial images paired with sagittal and coronal multi-planar reformations. In MRA maximum intensity projections were most frequently the initial set of images that was reviewed followed by the source coronal or axial extra- or intracephalic angiography images. Most striking was the observed difference between CTA and MRA in image quality and vessel visibility of the intracranial vessels. Scores for vessel visibility were significantly better for almost all intracranial vessels, and smaller arteries like the posterior communicating artery were only reliably detected by MRA. Interestingly, intracranially the unenhanced time-of-flight MR sequence appeared superior to the contrast-enhanced gradient-echo sequence; this sequence comparison, however, was not thoroughly studied here and reflects a personal opinion of the authors. Although MRA revealed better intracranial image quality and (small) vessel detection, all clinically relevant information could also be perceived from the CTA images.

Our study has several limitations. The number of patients included is not very high. However, for vessel visibility numerous, mostly bilateral vessels, often divided into subsegments, were separately analyzed, which resulted in a total number of 624 vessel segments that were compared
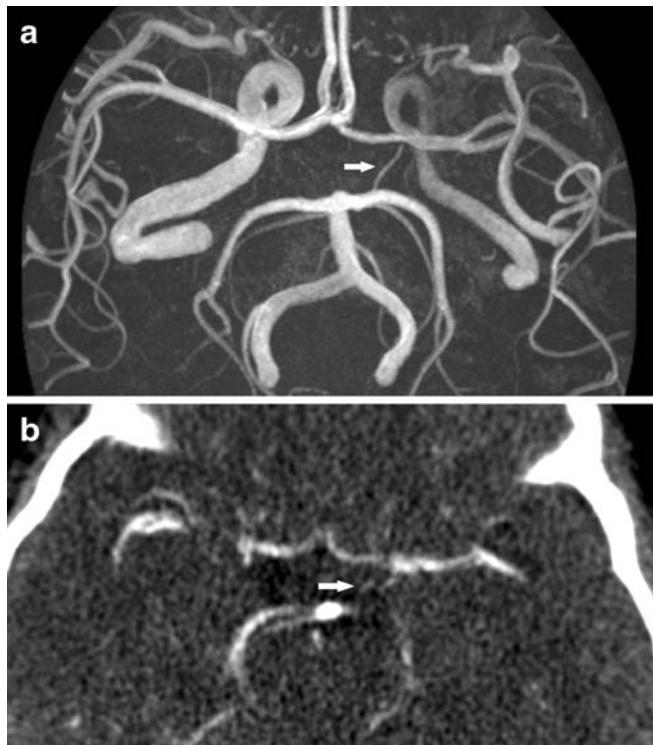
between the two imaging investigations. Moreover, the degree of stenosis of the carotid arteries was not analyzed and measured. This part, however, was left out as the still acknowledged gold standard DSA was not performed in all study participants. As mentioned above, previous studies already proved the potential of both CTA and MRA to reliably determine the degree of carotid stenosis. No inter- or intra-observer comparison was made; therefore, a consensus reading between two board certified radiologists with long-standing experience in cranial vessel analysis was performed. A future prospective study with a larger patient collective, inclusion of DSA data, high field MRI plaque imaging and dual-energy CT data is desirable and our focus.

Our results indicate that both DSCT and 3T-MRA are comparable at imaging both the extra- and intra-cranial arterial vessels and are helpful in diagnosis finding and pre-interventional planning. Although MRA proved to be superior in assessment of especially small intracranial arteries, all clinically relevant information needed for pre-interventional planning could be perceived from the DSCT examinations. Moreover, DSCT also allowed for dedicated depiction of carotid plaque calcifications. The two main CTA downsides are the radiation exposure and the administration of iodine-containing contrast media; these minor risks need to be balanced before DSCT can be recommended as an alternative to MRA in the pre-interventional assessment of carotid artery stenosis.

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