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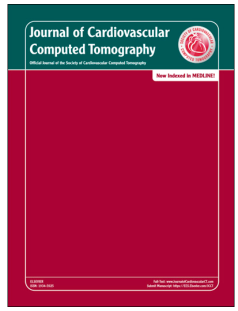

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Submillisievert CT angiography for carotid arteries using wide array CT scanner and latest iterative reconstruction algorithm in comparison with previous generations technologies: feasibility and diagnostic accuracy

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ABSTRACT:

Objectives: To assess evaluability and diagnostic accuracy of a low dose CT angiography (CTA) protocol for carotid arteries using latest Iterative Reconstruction (IR) algorithm in comparison with standard 100 kVp protocol using previous generation CT and IR.

Materials and Methods: 105 patients, referred for CTA of the carotid arteries were prospectively enrolled in our study and underwent CTA with 80 kVp and latest IR algorithm (group 1). Data were retrospectively compared with 100 consecutive patients with similar examination indications that had previously undergone CTA of carotid arteries with a standard 100 kVp protocol and a first generation IR algorithm (group 2). Image quality was evaluated with a 4-point Likert-scale. For each exam CT number, image noise, signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR) at level of common carotid artery (CCA), internal carotid artery (ICA) and at level of Circle of Willis and Effective Dose (ED) were evaluated. 62 Group 1 patients underwent a clinically indicated DSA and results were compared with CTA.

Results: No exams reported as not diagnostic. The overall mean CT number value of all arterial segments was above 450 HU in both groups. Significant lower noise, and higher SNR and CNR values were found in group 1 in comparison with group 2 despite the use of 80 kVp. In 62-group 1 patients studied by DSA, CTA showed in a segment-based analysis a sensitivity, negative predictive value and accuracy of 100%, 100% and 99% respectively. Mean ED in group 1 was 0.54±0.1 mSv with a dose reduction up to 86%.

Conclusions: CTA for carotid arteries using latest IR algorithm allows to perform exams with submillisievert radiation exposure maintaining good image quality, overall evaluability and diagnostic accuracy.

Keywords

Computed Tomography Angiography; Carotid arteries; atherosclerosis; dose reduction; Iterative reconstruction algorithm.

Keypoints

• Adaptive statistical iterative reconstruction (ASIR)-V allows

high-quality low-dose CT.

• Use of last generation CT scanner and ASIR-V allows high accuracy examinations.

• In comparison with ASIR, ASIR-V allows ED reduction up to 86%.

Abbreviations:

CAD Coronary artery disease

CTA Computed tomography angiography

CNR Contrast to noise ratio

DLP Dose length product

DSA Digital Subtraction angiography

ED Effective dose

IR Iterative Reconstruction

ROI Region of interest

SD Standard deviation

SNR Signal to noise ratio

1. INTRODUCTION

Atherosclerosis of large vessels is the most common pathophysiological mechanism inducing brain ischemia. Brain ischemia is a multifactorial event frequently related to brain embolization from different sources. Carotid arteries stenosis (CAS) is thought to be responsible for brain ischemia in 15-25% of all cases (1). Doppler ultrasound and other imaging techniques are the most effective diagnostic tools to detect CAS and to reduce the probability of a stroke [1, 2]. CT angiography (CTA) has been widely demonstrated to be an accurate method for detection of atherosclerotic lesions of carotid arteries and to assess the severity of stenosis [3]. The diagnostic applications of CTA have improved considerably in the last few years because of its high spatial resolution, novel reconstruction algorithms and specific dedicated reconstruction tools that have been progressively developed. Moreover CTA is often used in follow- up of previous carotid arteries stenting or surgical procedures.

Therefore, the radiation exposure associated with the increasing number of exams suggests the need for optimisation of established scan protocols for CTA aiming at reduction of the effective dose to the patients. There are several parameters affecting the radiation dose and in this regard, the most effective methods to lower radiation exposure are the reduction of tube voltage and current [4] using Iterative Reconstruction (IR) algorithms to avoid loss of image quality due to increased image noise. Several studies demonstrated the feasibility of CTA using these new first and second-generation iterative reconstruction algorithms to obtain low dose examinations without impairment of image quality [5-11]. Moreover the advent of new generation CT scan with wide detector 16-cm **Detector coverage** , has introduced higher volume acquisition modes with faster scan time.

To the best of our knowledge, accuracy of CTA of carotid arteries using wide-volume acquisition CT scanner and last generation adaptive IR algorithm has not been extensively assessed. Thus aims of this study are to assess feasibility and radiation exposure of a low dose scan protocol for CTA of carotid arteries using a wide array CT scanner, 80-kVp and third generation adaptive statistical iterative reconstruction algorithm – V (ASIR-V) in patients with suspected or known carotid artery disease, in comparison with standard 100 kVp protocol using first generation adaptive statistical iterative reconstruction algorithm. Moreover we evaluate the diagnostic accuracy of CTA in comparison with DSA as reference standard in patients scheduled for endovascular revascularization due to CTA positive for significant carotid stenosis.

2. MATERIALS AND METHODS

Written informed consent was obtained from all patients and the study protocol was approved by the Institutional Ethics Committee. We enrolled 105 patients referred to our hospital for diagnostic CTA of carotid arteries due to suspected carotid stenosis or follow-up of known carotid atherosclerosis (Group 1) that underwent CT examination with a 80 kVp scan protocol. Exclusion criteria were adverse events to contrast agents and impaired renal function (estimated glomerular filtration rate < 30 mL/min/1.73 m2). For comparison data regarding CT dataset of 100 consecutive patients with matching BMI values and similar examination indications that had previously undergone CTA of carotid arteries with a standard 100 kVp protocol and a first generation adaptive statistical iterative reconstruction algorithm were retrospectively identified from our hospital database (Group 2).

2.1 IMAGING PROTOCOL

The CTA was performed in group 1 with a 256-slice Revolution CT scanner (GE Healthcare, Milwaukee, WI) using the following parameters: detector configuration 256 × 0.625 mm, gantry rotation time 0.28 seconds, 0.922 Pitch, 80 kVp and automated tube current modulation along the Detector coverage (mA range: 120-500) with a 23 Noise Index. Patients of group 2 underwent CT with a 64-slice Discovery CT 750 HD (GE Healthcare, Milwaukee, WI) and with 100 KVpp tube voltage, 64 x 0.625mm slices configuration, 500 ms gantry rotation time, 0.984 Pitch and automated tube current modulation along the Detector coverage (mA range: 213-600) with a 18-20 Noise Index. All patients received a 50-ml bolus of contrast medium (Iodixanol 320 mg/ml, GE Healthcare) through an ante-cubital vein at an infusion rate of 5 ml/s, followed by 50 ml of saline solution at the same rate. The bolus tracking technique was used to synchronize the arrival of contrast material at the aortic arch with the start of acquisition. Data were obtained from the aortic arch up to the circle of Willis in the caudo-cranial direction. In group 1 patients a last generation post-processing adaptive statistical iterative reconstruction algorithm V (ASIR V, GE Healthcare, Milwaukee, WI) was used at 50% level while in group 2 images were post processed using a first generation adaptive statistical IR (ASIR) at 50% level.

2.2 CTA IMAGE RECONSTRUCTION AND ANALYSIS

The obtained data sets of each CTA were transferred to a dedicated image-processing workstation (Advantage Workstation Version 4.6, GE Healthcare, Milwaukee, WI). CTA images were evaluated by two experienced readers, blinded to the scan protocol, both with ≥ 9 years of clinical experience in CTA performance and analysis, in terms of image quality and presence of artefacts. The reconstructed 0.625-mm axial images were also processed with a dedicated vessel analysis software to determine the grade of ICA stenosis (Carotids analysis, GE Healthcare, Milwaukee, WI). The evaluating radiologists performed the digital image processing to obtain both the multiplanar images and the vessel analysis. The software automatically detected the vessel centerline and computed cross-sectional area and minimum and maximum diameters at each point. The user defined the minimum lumen area and the reference area according to ECST criteria. For any disagreement on data analysis between the two readers, consensus agreement was achieved. To evaluate objective image quality, the mean arterial CT number and image noise (defined as the standard deviation (SD) of the vessel density) were measured by a circular region of interested (ROI) accurately sized to not exceed vessels borders, placed in the center of the vessel lumen at the right and left common carotid arteries (CCA) (1 cm below the bifurcation), distal internal carotid artery (ICA) (3 cm above the bifurcation), middle cerebral artery (MCA) and basilar artery (BA) segments for each case. Moreover for each patient the vertebral arteries (VA) at their middle third were evaluated. Arterial CT number values above 400HU were interpreted as sufficient. The signal to noise ratio (SNR) was determined by dividing the mean CT number within the lumen of the vessels for the related image noise. The contrast to noise ratio (CNR) was determined for the given segments as the difference between the mean intra-arterial CT number and the mean CT number of the sternocleidomastoid muscle divided by the intra arterial noise. Subjective image quality assessment was evaluated by means of a 4-grade scale (4, excellent; 3, good, mild artifacts not impairing image quality; 2, fair, presence of major artifacts; 1, poor, not evaluable). Artifacts (beam-hardening, movement artifacts, etc) were grouped into 4 classes (4, no artifacts; 3, mild artifacts not affecting diagnostic value; 2, artifacts affecting diagnostic value; 1, severe artifacts, not diagnostic). Artifacts caused by dental hardware (in not removable denture) were not considered. Carotid stenoses were evaluated using the European Carotid Surgery Trial (ECST) criteria. Grades of stenosis were divided into three groups: mild (20%-50%), moderate stenosis (> 50%–69%) and severe stenosis (70%–99%). Occluded segments were excluded from the study.

2.3 DIGITAL SUBTRACTION ANGIOGRAPHY

Accuracy was tested in a subgroup of 62 symptomatic patients from Group 1 scheduled for clinically indicated endovascular revascularization due to CT findings. DSA was performed using transfemoral / transbrachial approach. The aortic arch was imaged in 45° left anterior-oblique view as well as the common carotid arteries, the vertebral arteries and the subclavian arteries. The common carotid arteries were selectively catheterized. Images from both carotid artery bifurcations were obtained in anteroposterior, lateral, and 2 oblique projections. The intracranial circulation was also included in postero-anterior and lateral projections. The preferred oblique projections used were the postero-anterior view and the 45° left and right oblique for the left and right ICA, respectively. The angiograms were performed and analyzed by an experienced interventional cardiologist and a vascular surgeon.

2.4 RADIATION DOSE

Radiation dose was evaluated for each CT scan. The scanner-generated Volume CT dose index (CTDIvol) and the dose length product (DLP) were recorded including all the scan series, comprehensive of the planning scans and the bolus tracking scan . DLP was multiplied with the

International Commission on Radiological Protection conversion factor for Head CT (0.0022 mSv/mGy.cm; 16 cm head phantom) to calculate effective dose (ED) [12,].

2.5 STATISTICAL ANALYSIS

Statistical analysis was performed using SPSS version 24 software (SPSS, Chicago, IL). Continuous variables were expressed as mean±SD, and discrete variables were expressed as absolute numbers and percentages. Differences in mean values between the two groups with normally distributed data were determined by two-tailed independent t-test The overall evaluability (ratio of the number of evaluable carotid artery segments to number of all carotid artery segments), sensitivity, specificity, negative predictive value, positive predictive value and accuracy were calculated versus DSA with a cut-off of artery stenosis ≥70%, including all common and internal carotid segments. The Spearman correlation and Bland-Altman analysis were used to compare CTA vs DSA. Linear regression analysis was applied with the DSA reference as the dependent variable to estimate the intermethod agreement by a regression coefficient, and scatterplots with regression lines were created. Interobserver agreement for image quality and carotid stenosis area measurements was evaluated with Spearman rank correlation coefficient and Cohen weighted K coefficients according to the following equation: (observed agreement – chance agreement)/(1-chance agreement). K-values were interpreted as follows: absence of agreement ≤0, poor agreement <0.20, fair agreement 0.21 – 0.40, moderate agreement 0.41 – 0.60, good agreement 0.61–0.80 and excellent agreement >0.80. A two tailed p-value <0.05 was considered statistically significant.

3. RESULTS

The baseline characteristics of the study groups are listed in **Table 1**. All the examinations were performed without significant complications during the procedure. For all patients image quality was found to be sufficient for good diagnostic quality in all arterial segments and no exams were classified as not diagnostic due to severe artifacts. In group 1 two-hundred and ten carotid arteries were evaluated with a total of 717 patent arterial segments (208 CCA, 204 ICA, 200 MCA and 105 BA) and 8 occluded segments. Stented segments were 32. 196 VA were evaluated as patent (14 vessels were classified as occluded or not evaluable due to very small caliber). Overall mean image quality in a 4-grade scale (4 excellent – 1 poor) was in Group 1 and Group 2 3.8±0.3 and 3.3±0.4 respectively while mean artifacts assessment value (4, no artifacts – 1, not diagnostic) was 3.3 ±0.6 and 3.0±0.5 respectively. In group 2 a total of 681 patent arterial segments (195 CCA, 190 ICA, 196 MCA and 100 BA) and 10 occluded segments were found. Stented segments were 28. 190 VA were evaluated as patent (10 vessels were classified as occluded or not evaluable due to very small caliber).

Objective image quality parameters for different arterial segments are listed in **Table 2**. The overall mean CT number value of all arterial segments was above 400 HU for both group. Moreover in group 1 the overall mean CT number values were slightly superior than in group 2 with an average value above 500 HU. The highest and lowest arterial CT number values were detected in CCA and in the BA respectively with slightly higher values in the right arterial segments. Even for the Willis circle, measurements at the level of the MCA showed mean CT number values over 580 HU and mean image noise values similar to internal carotid arteries (**Fig 1**). Mean image noise was significantly lower in group 1 except for intra cranial segments in which no significant differences were found. Significant differences were instead found in all arterial segment between the two groups concerning SNR and CNR values**.** Evaluation of arterial segments for the presence of stenosis revealed mild and moderate stenosis respectively in 20 and 22 segments for group 1 and in 18 and 19 segments in group 2. In the sub-group of Group 1 patients that underwent clinically indicated DSA, CTA showed for arterial stenosis assessment in a segment-based analysis a sensitivity, negative predictive value and accuracy of 100%, 100% and 99% respectively. Specificity and positive predictive value were 98% and 97% respectively. In a vessel based analysis CT showed an overall sensitivity, specificity, negative predictive value, positive predictive value and accuracy of 100%, 96%, 100%, 96% and 98% respectively (as shown in **Table 4a**). In a subgroup analysis including only patients with high BMI (>29 kg/m^2) and with heavily calcified plaques, in comparison with DSA, CT maintained a good diagnostic performance showing sensitivity, specificity and accuracy of 100%, 94%, 95% and 100%, 97% and 97% respectively (Table 4b). Degree of stenosis on CTA closely correlated with DSA (r=0.98) (**Figure 2**). In comparison with DSA, CTA was able to detect significant stenosis in 60 vessels confirmed by DSA while in 2 vessels CTA slightly overestimated stenosis degree retrospectively due to severe calcifications (CTA derived stenosis 70% and 75% versus DSA evaluation of 55% and 60% stenosis respectively). Plaque ulceration was depicted by CT in 9 patients and in all cases the finding was confirmed by DSA. Good correlation for group 1 inter-observer vessel measurements reproducibility of the minimum lumen area (r=0.93) are shown in **Figure 3**. The Kappa value for inter-observer agreement in classifying CTA image quality of carotid arteries in Group 1 and Group 2 was 0.86 and 0.85 respectively. CT carotid stenosis reconstructions and comparison with DSA images are shown in **Figure 4 and 5.** Mean CTDIvol and DLP were significantly lower in group 1 in comparison with group 2 with average values of 2.65±0.49 mGy and 100.7±20.1 mGycm and 20.5±2.4 mGy and 735.37±103.2 mGycm respectively with an overall mean effective dose reduction up to 90% (0.18±0.09 mSv versus 1.61±0.22mSv)

4. DISCUSSION

The main result of this study is that the combined use of wide array CT scanner with 80kVp and last generation IR algorithm enable very low dose diagnostic visualization of carotid arteries without image quality impairment, maintaining high diagnostic performance with an accuracy approaching 100% in comparison with DSA as gold standard. Moreover in comparison with previous generation 64-slices CT scanner using first generation IR algorithm a dramatic dose reduction approaching 90% is achievable. Besides the mean cumulative dose value achieved by our 80 kV protocol is clearly below the average dose value reported for same CT examinations in the European Dose Reference Levels (2.52 mSv) (13) CT has been shown to be an accurate method for detection of atherosclerotic lesions of carotid arteries and to assess the severity of stenosis [1-3]. The European Society of Cardiology guidelines on the diagnosis and treatment of peripheral artery diseases list CTA in class of recommendation and level of evidence “1A” because its excellent sensitivity and specificity for the detection of carotid artery stenosis. Moreover CTA is considered as first choice imaging modality together with ultrasound and Magnetic Resonance in patients with or without recent symptoms of stroke or transient ischemic attack (TIA). However the use of CTA is not recommended for screening purposes due to the high doses of radiation used [14]. Furthermore limitations related to use of CTA in uncooperative (moving) patients and due to low specificity are also reported in international guidelines [15]. The increasing number of CT procedures for diagnosis of cardiovascular diseases imposes to pay attention to the effects of radiation exposure, in particular in those patients that need to undergo repeated CT exams throughout clinical follow-up. In literature most of the studies about feasibility of low dose CTA for carotid arteries report use of 100 kVp protocols. Recently the implementation of IR algorithms allowed the use of 70 kVp or 80 kVp protocols with significant effective dose reduction as reported in recent studies. Chen et al. [8] reported significant dose reduction using 70 kVp and IR algorithm even if the study was only limited to the intra cranial vessels. Recent studies by Eller [16] and Kayan [17] reported feasibility of low kVp protocols resulting in significant dose reduction while preserving image quality. In both studies the reported significantly increased noise level of the images was compensated by increased iodine contrast, resulting in a comparably high or improved CNR. Nevertheless no Iterative Reconstruction algorithms were used to further reduce image noise and optimize CNR. In this regard our results appear consistent with data recently published by Leithner et al. using an advanced modeled iterative reconstruction algorithm even in presence of a slight lowe tube voltage used (18). Moreover few studies exist including diagnostic performance of these new scan protocols in comparison with previous generation IR algorithms and DSA. Our study demonstrates that using low kVp, modulated mA and ASIR-V reconstruction algorithm, result in good vessel CT number (above 500 HU), significant noise lowering and dramatic reduction in effective dose (< 1 mSv) without loss of image quality in comparison with standard protocols using higher tube voltage values. Furthermore we demonstrated effectiveness of this protocol in comparison with DSA as reference standard, with excellent sensitivity, specificity and accuracy (100%, 96% and 98% respectively) despite a very low dose. Even in case of calcified plaques and obese patients our results showed high sensibility, specificity and accuracy. Moreover the overall good image quality we achieved can also be related to the use of wide array CT scanner. Faster scan time (about 2 seconds) results in less artifacts in comparison with previous generation CT scanner (about 6 seconds) due to a lowest incidence of movement artifacts even in not completely cooperative patients. The latest release of IR algorithm available in our department, ASiR-V, differs from previous IR generations by de-emphasizing system optics modeling and using more advanced noise and object modeling as well as introducing physics modeling. Through a reduced focus on optics modeling, ASiR-V reconstructions can be generated in significantly less time [19]. This feature results in a prompt reconstructed images availability (in comparison with other IR such as Model Based Iterative Reconstruction [7]) that allows use of this scan protocol even in case of urgent exams. These data could support the possibility of future larger studies to revisit the existing flowchart and guidelines regarding the limitations of CTA of carotid arteries concerning the problems related to the use of ionizing radiations.

4.1 STUDY LIMITATIONS

Some limitations of this study should be acknowledged. First the ASIR-V is only available with this new CT scanner. Thus a retrospective comparison with data regarding image quality parameters of 64-slices MDCT with first generation IR algorithm was done and this could lead to inclusion bias. Second the differences regarding motion and respiratory artifacts during the scan were quite expected due to the significant difference in scan time between the two groups. Third we didn't perform a comparison with different imaging modalities such as MRI. Fourth a relative a small number of patients underwent DSA and this could limit the diagnostic accuracy assessment. Moreover only in group 1 an accuracy evaluation was performed as well as an evaluation of measurements reproducibility. Fifth the used conversion factors for ED evaluation are calculated for specific body regions or CT scan ranges (e.g. cervical spine) that may not match the clinical scan range used in real life.

5. CONCLUSIONS

In conclusion, our study demonstrates that the combined use of 80 kVp, 160 mm coverage CT scanner and new IR algorithm ASIR-V in CTA of the carotid arteries allows scan protocol with submillisievert effective dose while maintaining good image quality and excellent diagnostic accuracy (compared to DSA as gold standard reference). Furthermore in comparison with previous generation 64-slice CT scanner using standard 100 kVp tube voltage and first generation adaptive statistical iterative reconstruction algorithm, this protocol could lead to an overall mean effective dose reduction up to 86%. Our results suggest that further data about patient safety might be achieved by studies combining dose saving techniques with lower contrast protocols and this could maybe support the revisiting of some aspects of the current guidelines regarding the use of carotid arteries CTA in the management of patients at risk of brain ischemia lowering the problems related to the use of ionizing radiations.

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FIGURE LEGENDS:

Figure 1: Axial images showing measurement of mean CT number values and noise (sd) of right and left CCA (A), ICA (B), basilar artery (C) and middle cerebral artery (D).

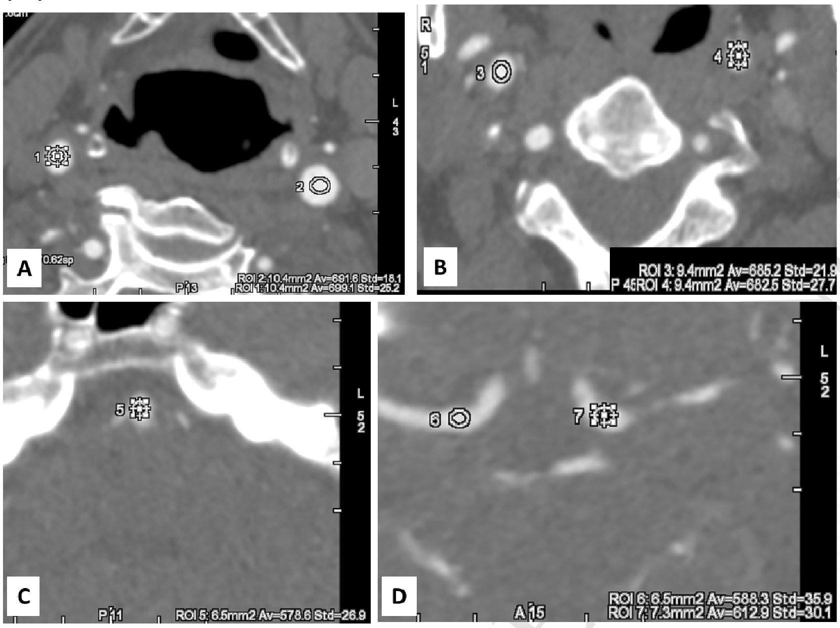


Figure 2: Pearson correlation (upper panel) and Bland-Altman analysis (lower panel) between CTA and DSA assessment of carotid arteries stenosis

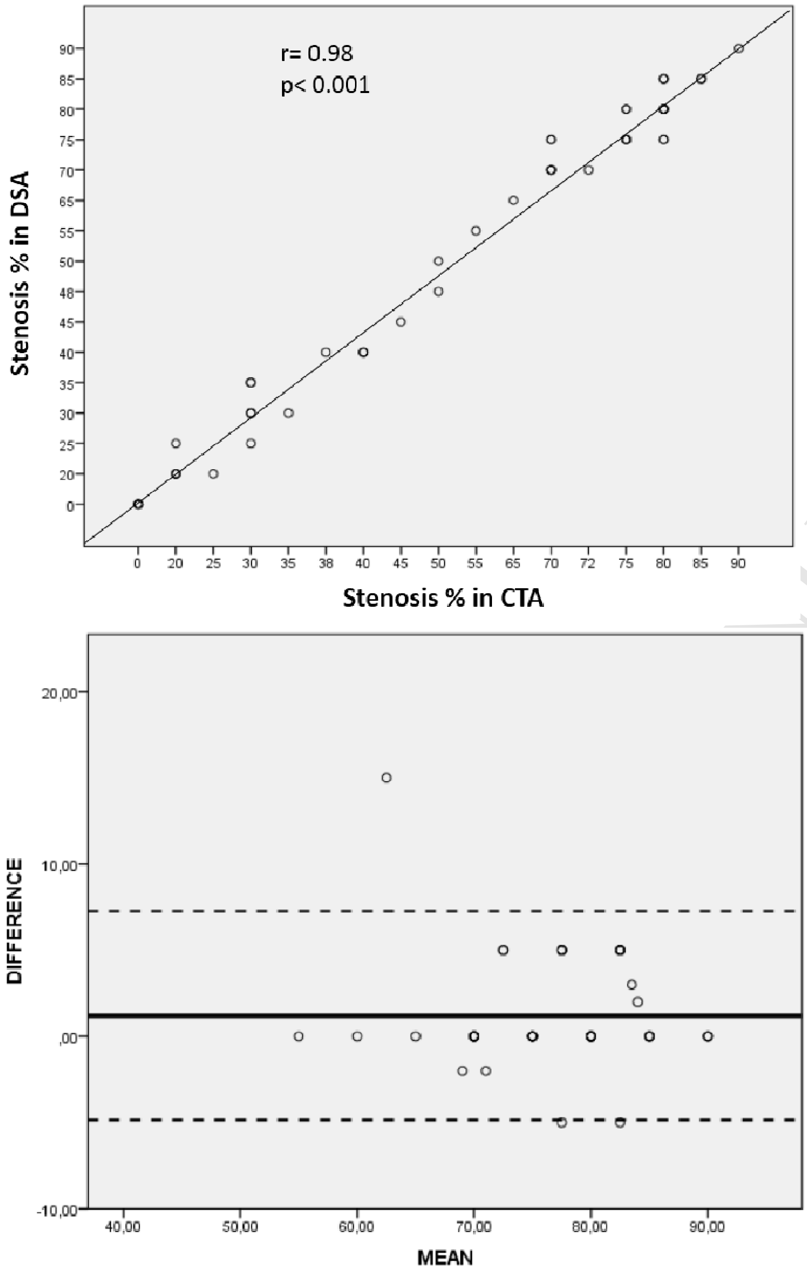


Figure 3: Data reproducibility: Pearson correlation (upper panel) and Bland-Altman analysis (lower panel) for interobserver CT measurements of stenosis minimum lumen area (mm^2)

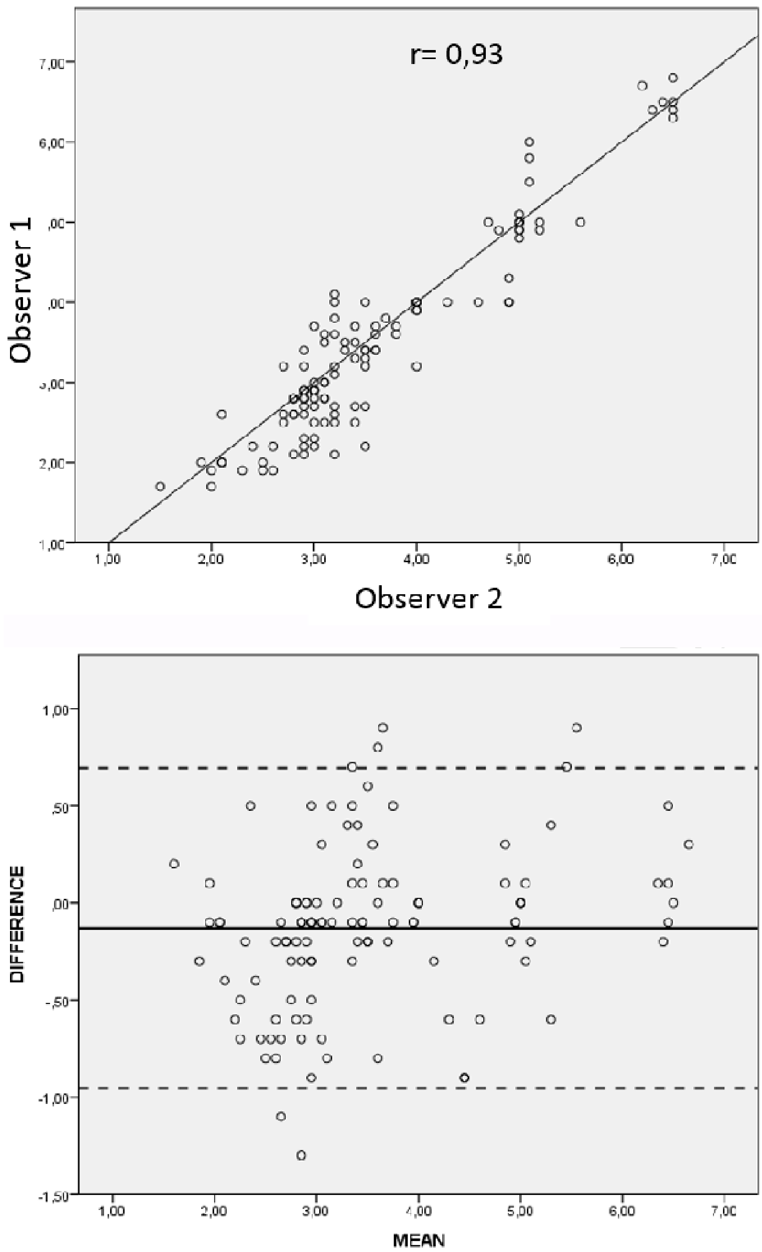


Figure 4: Imaging of severe carotid stenosis in 68 yo patient (BMI 27 kg/m^2, 80 kVp, ED: 0.49 mSv). Reconstruction by volume rendering (A), MPR (B) and DSA image (C) in the same view is shown.

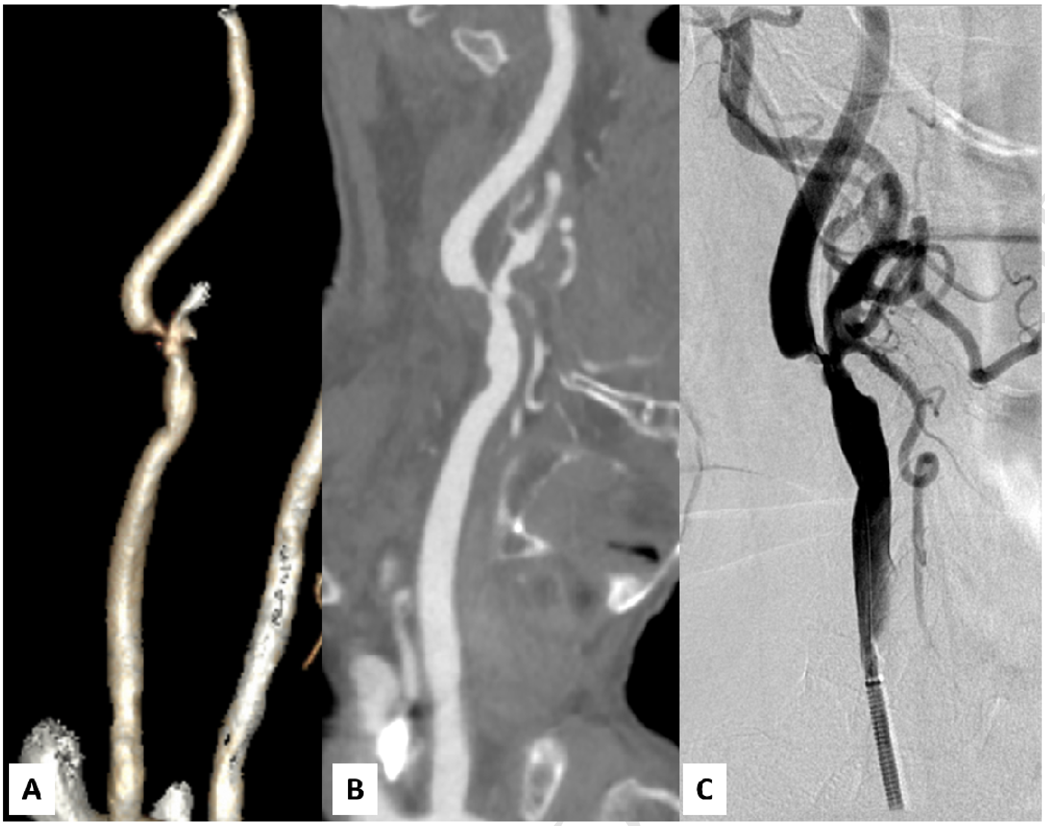
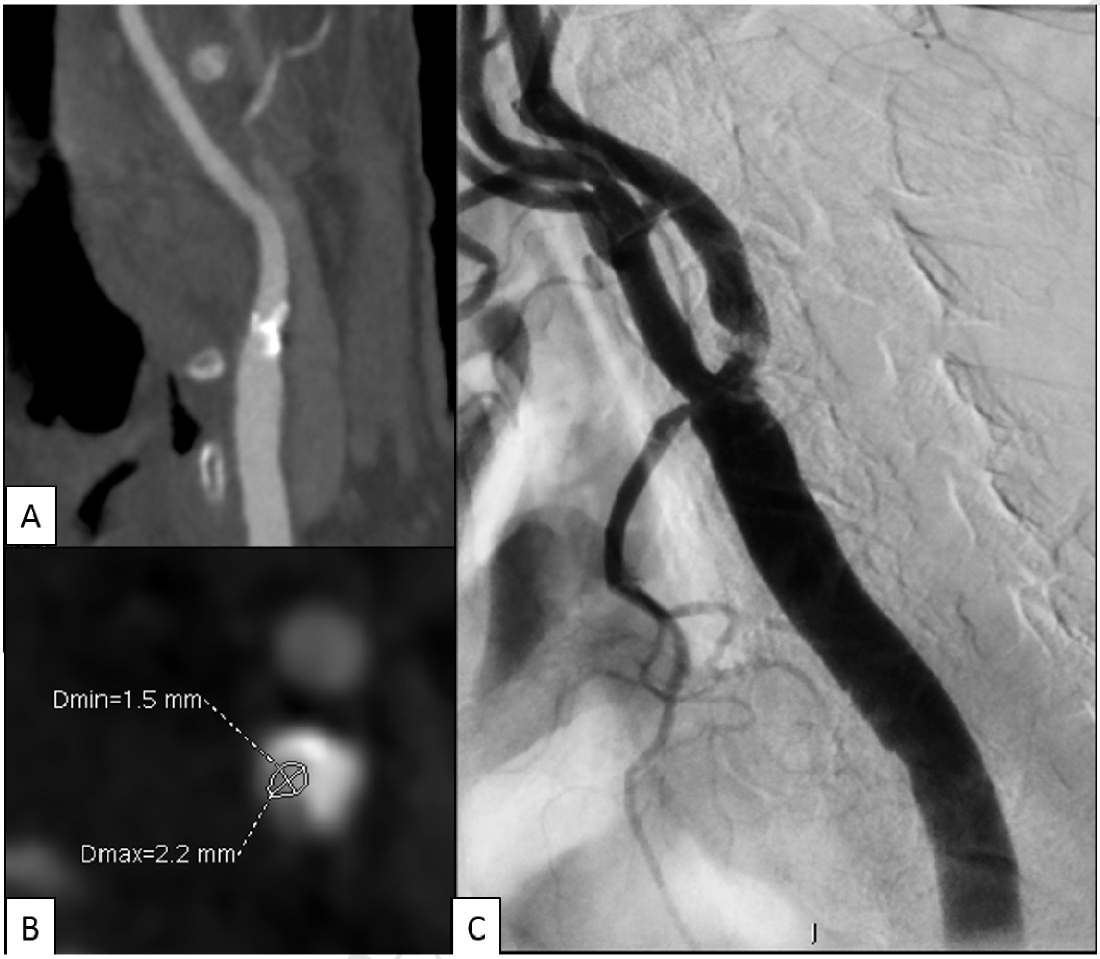


Figure 5: A 80 years old patient with severe stenosis of right ICA due to calcified plaque. Image shows CT multiplanar reconstruction (A), axial image for stenosis area assessment (B) and DSA confirming severe stenosis (C).



TABLES:

Table 1: Clinical characteristics of study population

Clinical characteristics	Group 1	Group 2	p-value
Number of patients, n	105	100	1
Gender (men/women)	65/40	64/36	0.5
Age (years)	73.6±8.0	71.7±10.3	0.5
Body mass index (kg/m^2)	25.1±3.9	26±4.2	0.5
BSA (m^2)	1.72±0.4	1.71±0.2	0.5
LVEF (%)	52.8±3.7	54.2±0.1	0.5

Data are presented as mean ± SD or absolute number.

HU: Hounsfield units; BSA: Body Surface Area. LVEF: left ventricle ejection fraction.

Table 2: Objective image quality parameters

Table 2a: lumen CT number values

Lumen CT number (HU)	**Group 1 (ASIR V)**	**Group 2 (ASIR)**	**p-value**
Common Carotid Artery			
Right	724.1 ±151.5	556.20±63.01	<0.001
Left	721.9 ±147.7	567.43±72.61	<0.001
Internal Carotid Artery			
Right	689.2±156.1	499.95±50.16	<0.001
Left	682.1±152.5	502.23±61.41	<0.001
Middle Cerebral Artery			
Right	592.2±135.2	506.7±66.3	<0.01
Left	580.7±127.8	534.5±78.9	<0.01
Basilar Artery	552.8±118.7	506.8±36.4	<0.01
Vertebral artery			
Right	535.1±85.2	485.5±51.2	<0.001
Left	538.7±97.8	497.2±40.0	<0.001

Values are expressed as mean±standard deviation. HU: Hounsfield Units. SNR: signal to noise ratio. CNR: contrast to noise ratio.

Table 2b: vessel image noise values

NOISE	Group 1 (ASIR V)	Group 2 (ASIR)	p-value
Common Carotid Artery			
Right	19.8 ±9.1	23.8±2.3	<0.01
Left	20.1 ±3.4	23.3 ± 4.4	<0.01
Internal Carotid Artery			
Right	21.6±6.7	25.2 ± 5.8	<0.01
Left	20.8±5.5	24.9 ± 6.4	<0.01
Middle Cerebral Artery			
Right	24.5±6.0	24.7±9.2	<0.1
Left	22.7±11.2	23.1±8.9	<0.1
Basilar Artery	27.2±5.3	29.5±6.4	<0.1
Vertebral artery			
Right	24.4±8.0	26.1±8.3	<0.01
Left	23.7±9.1	26.5±9.2	<0.01

Values are expressed as mean ± standard deviation.

Table 2c: vessel signal-to-noise-values

SNR	Group 1 (ASIR V)	Group 2 (ASIR)	p-value
Common Carotid Artery			
Right	45.3 ±29.8	34.5 ± 18.8	<0.001
Left	40.2 ±16.7	32.2±14.2	<0.001
Internal Carotid Artery			
Right	35.8±22.1	21.3±12.3	<0.001
Left	32.0±15.1	22.1±9.8	<0.001
Middle Cerebral Artery			
Right	31.1±22.9	26.9±12.0	<0.01
Left	30.8±20.0	27.7±18.2	<0.01
Basilar Artery	24.7±16.4	20.1±9.2	<0.01
Vertebral artery			
Right	26.1±21.3	20.9±8.1	<0.001
Left	25.8±20.0	20.7±6.2	<0.001

Values are expressed as mean ± standard deviation. SNR: signal-to-noise ratio

Table 2d: vessel contrast-to-noise-values

CNR	Group 1 (ASIR V)	Group 2 (ASIR)	
Common Carotid Artery			
Right	40.3 ±27.8	30.5±17.1	<0.001
Left	35.8 ±15.3	29.1±11.5	<0.001
Internal Carotid Artery			
Right	31.6±21.4	22.6±11.0	<0.001
Left	28.6±13.1	23.8.1±16.5	<0.001
Middle Cerebral Artery			
Right	26.9±20.0	24.6±10.1	<0.01
Left	26.7±18.2	23.8±11.4	<0.01
Basilar Artery	22.1±14.2	21.3±12.4	<0.01
Vertebral artery			
Right	25.9±10.1	22.2±11.0	<0.001
Left	26.7±12.2	21.5±12.2	<0.001

Values are expressed as mean ± standard deviation. CNR: contrast-to-noise ratio

Table 4a: Comparison of diagnostic accuracy of CTA vs. DSA for detection of carotid artery stenosis > 65% (excluding occluded vessels)

Segment-based Analysis									
No. of segments	**No of TN Findings**	**No of TP Findings**	**No of FN Findings**	**No of FP Findings**	**Sensitivity**	**Specificity**	**NPV**	**PPV**	**Accuracy**
246	169	75	0	2	100 (100-100)	98 (97-100)	100 (100-100)	97 (93-100)	99 (98-100)
Vessel-based Analysis									
No. of vessels	**No of TN Findings**	**No of TP Findings**	**No of FN Findings**	**No of FP Findings**	**Sensitivity**	**Specificity**	**NPV**	**PPV**	**Accuracy**
122	60	60	0	2	100 (100-100)	96 (92-100)	100 (100-100)	96 (92-100)	98 (96-100)

In parentheses data are 95% confidence interval. FN = false-negative, FP = false- positive, NPV = negative predictive value, PPV = positive predictive value, TN = true-negative, TP = true-positive.

Table 4b: Comparison of diagnostic accuracy of CTA vs. DSA for detection of carotid artery stenosis > 65% (excluding occluded vessels) in subgroups of patients with high body mass index and in case of calcified plaques

Vessel-based Analysis in patients with BMI > 29									
No. of segments	**No of TN Findings**	**No of TP Findings**	**No of FN Findings**	**No of FP Findings**	**Sensitivity**	**Specificity**	**NPV**	**PPV**	**Accuracy**
22	17	4	0	1	100 (100-100)	94 (83-100)	100 (100-100)	80 (45-100)	95 (86-100)
Vessel-based Analysis in heavily calcified plaques									
No. of vessels	**No of TN Findings**	**No of TP Findings**	**No of FN Findings**	**No of FP Findings**	**Sensitivity**	**Specificity**	**NPV**	**PPV**	**Accuracy**
42	33	8	0	1	100 (100-100)	97 (91-100)	100 (100-100)	88 (68-100)	97 (86-100)

In parentheses data are 95% confidence interval. BMI= Body Mass Index FN = false-negative, FP = false- positive, NPV = negative predictive value, PPV = positive predictive value, TN = true-negative, TP = true-positive.

Table 5: Radiation dose

	Group 1 (ASIR V)	Group 2 (ASIR)	p-value
CTDI vol (mGy)	2.65±0.49	20.5±2.4	<0.001
DLP (mGycm)	100.7±20.1	735.3±103.2	<0.001
ED (mSv)*	0.18±0.09 mSv	1.61±0.22mSv	<0.001

Data are means ± standard deviations. Cm: centimeter; CTDIvol: Volume CT Dose Index, DLP: Dose Length Product, ED: Effective Dose, mGy: Milligray, mSv: Millisievert.