International Journal of General Medicine

Dovepress
open access to scientific and medical research

Open Access Full Text Article

ORIGINAL RESEARCH

Computed Tomography Angiography in the Diagnosis of Subclavian-Vertebral Artery Steal

Yanru Chen[1,*], Wenqi Li[1,*], Kunhua Li[2]

[1]Neurology Department, The Second Affiliated Hospital of Chongqing Medical University, Chongqing, People's Republic of China; [2]Radiology Department, The Second Affiliated Hospital of Chongqing Medical University, Chongqing, People's Republic of China

*These authors contributed equally to this work

Correspondence: Yanru Chen, Neurology Department, The Second Affiliated Hospital of Chongqing Medical University, No. 74 Linjiang Road, Yuzhong District, Chongqing, 400010, People's Republic of China, Tel +86 13983100640, Email chenyanru@cqmu.edu.cn

Purpose: Computed tomography angiography (CTA) is commonly used in the diagnosis and evaluation of subclavian steal (SS). However, the abnormal manifestations of vertebral artery (VA) in SS on CTA are vastly under-recognized and prone to misdiagnosis. We reported for the first time the abnormal CTA manifestations of VA in SS, and evaluated the value and pitfalls of CTA in the diagnosis of SS, aiming to avoid misdiagnosis and facilitate correct diagnosis of SS using CTA.

Patients and Methods: This study retrospectively included 19 patients diagnosed with SS using carotid duplex sonography (CDS) and digital subtraction angiography (DSA) between 2018 and 2022 at a tertiary neurology clinic in Chongqing, China. Their CDS, DSA and CTA results were collected and analyzed. The diagnostic consistency between CTA and DSA in grading subclavian artery stenosis was evaluated, and the CTA manifestations of VA were summarized.

Results: All patients presented subclavian steno-occlusion on the affected side, without steno-occlusion of the contralateral subclavian artery or bilateral VA on DSA. A high concordance was observed between CTA and DSA in grading subclavian artery stenosis (Kappa = 0.825, $P = 0.000$). However, only 26.3% of patients presented normal VA on CTA, whereas 73.7% of patients presented shallow VA ipsilateral to subclavian steno-occlusion. A 28.6% of patients with shallow VA were misdiagnosed as having vertebral arteriopathy. The presence of shallow VA had no significant correlation with age, gender, severity of subclavian artery stenosis, diameter of VA or model of CT scanner (all $P>0.05$). Although not statistically significant, the incidence of shallow VA increased with higher SS grade.

Conclusion: Carotid CTA is highly accurate for diagnosing subclavian steno-occlusion, whereas shallow VA is the pitfall of CTA in diagnosing SS. It is important to improve the recognition of shallow VA to avoid misdiagnosis.

Keywords: subclavian steal, subclavian artery, vertebral artery, digital subtraction angiography, ultrasonography

Introduction

Subclavian-vertebral artery steal, also known as subclavian steal (SS), refers to the phenomenon of retrograde blood flow in the vertebral artery (VA) resulting from significant stenosis or occlusion of the ipsilateral subclavian artery (SA) or innominate artery (IA) proximal to the origin of VA, which may cause severe vertebrobasilar ischemia.[1,2] The prevalence of SS is between 0.6% and 6.4%,[3–5] and 7.4–19.1% of patients are symptomatic.[5,6]

Carotid duplex sonography (CDS) is regarded as the first-line imaging modality for detecting SS. However, because the abnormal spectral waveforms of VA suggestive of SS can be observed in other conditions such as VA hypoplasia and steno-occlusion of proximal VA,[7,8] and CDS sometimes fails to detect SA stenosis due to the deep intrathoracic location of the lesion and is limited in grading SA stenosis,[9] the diagnosis of SS requires the confirmation of steno-occlusion of SA or IA via angiographic techniques (MR angiography, computed tomography angiography [CTA] or digital subtraction angiography [DSA]). Although DSA is the gold standard for diagnosing arterial stenosis, it is commonly used only in patients requiring interventional treatment because it is invasive and expensive. MR angiography or CTA is commonly used in the diagnosis of SS. However, studies on CTA manifestations of SS so far are scarce, and the abnormal manifestations of VA in SS on CTA are vastly

Received: 31 July 2022
Accepted: 10 October 2022
Published: 25 October 2022

under-recognized and prone to misdiagnosis. This study summarized the CTA manifestations of SS and reported the abnormal CTA manifestations of VA in SS, aiming to facilitate correct diagnosis of SS by CTA and prevent misdiagnosis.

Materials and Methods

Patients

Patients diagnosed with SS using CDS and DSA and undergoing carotid CTA examination in the Second Affiliate Hospital of Chongqing Medical University from December 2018 to March 2022 were retrospectively included in this study. Patients with moderate stenosis or greater in any segment of the VA were excluded. Age, gender, clinical characteristics and neuroimaging findings, including CDS, DSA and CTA of all patients, were collected and analyzed. The medical ethics committee of the Second Affiliate Hospital of Chongqing Medical University approved the study's design and protocols (number (2019)321). Informed consent was waived because of this study's retrospective design.

Ultrasonic Examination

CDS was performed using a color-coded ultrasound system (MVU-6300, Delica Medical, China) equipped with a linear array probe (6–16 MHz) and a convex array probe (2–6-MHz). The bilateral carotid arteries (including common carotid artery, internal carotid artery, external carotid artery, VA, SA and IA) of the patients lying in the supine position were examined using the standard protocols. The ultrasound images were obtained with B-mode, color and spectral Doppler. Gain, depth, pulse-repetition frequency and wall filter were adjusted to the appropriate conditions. The size of the Doppler sample volume was adjusted to 1/3rd–1/4th of the detected vessel. The Doppler angle was adjusted to <60°. All CDS were performed by two experienced qualified sonographers (Yanru Chen and Wenqi Li) and the results were reviewed by one single sonographer (Yanru Chen) before the ultrasound reports were issued.

SS was categorized into three grades based on the waveform of VA:[9] Grade 1 (occult steal) refers to antegrade flow with a midsystolic notch; Grade 2 (partial steal) refers to the bidirectional blood flow; and Grade 3 (complete steal) refers to a completely reversed flow. The spectral waveform and stenosis degree of the ipsilateral SA were carefully examined, and the hyperemia-ischemia cuff test was conducted when VA showed any of the three types of waveforms. SS was diagnosed when the VA waveform changed to a more aberrant morphology, including a higher-grade steal or an increased velocity of reversed systolic flow upon a rapid deflation of the cuff.

The degree of SA stenosis was stratified into four categories based on the B-mode and velocity criteria: (i) mild (<50%) stenosis was considered when SA peak systolic velocity (PSV) is normal or slightly elevated (<240 cm/s) with normal spectral waveform, and plaque or lumen narrowing is visible on B-mode and color Doppler sonography; (ii) moderate (50–69%) stenosis was diagnosed when SA PSV ≥ 240 cm/s,[10] the ratio of stenotic PSV to distal PSV (PSVr) is 2.0–4.0,[11] and plaque or lumen narrowing is visible sonographically. Additional criteria include abnormal waveforms (eg, disturbed or turbulent flow, monophasic change) at stenotic site and normal waveform distally; (iii) severe (≥70%) stenosis was diagnosed when SA PSV ≥ 343 cm/s and PSVr ≥ 4.0,[12] and markedly narrowed lumen is visible sonographically. Additional criteria include dampening waveform or pulsus parvus and tardus distal to the stenotic site; (iv) occlusion was suspected when there is no detectable patent lumen at B-mode and no flow on spectral and color Doppler sonography.

The side and grade of SS, degree of SA stenosis, and diameter of bilateral VA of each patient were documented.

DSA Examination

DSA was performed on a biplane angiography system (Artis Q, Siemens, Germany; or Allura Xper FD20, Philips, the Netherlands). Four-vessel cerebral angiography was performed on each patient by skilled interventional neuroradiologists using a transfemoral approach with standard diagnostic catheters. The North American Symptomatic Carotid Endarterectomy Trial (NASCET) method was used to classify the degree of artery stenosis into four categories:[13] mild (30–49%), moderate (50–69%), severe (70–99%) and occlusion. The presence of steno-occlusion of SA or IA proximal to the origin of the affected VA confirmed the diagnosis of SS. Reversed blood flow in the affected VA verified SS, but it was not essential for diagnosing SS. All the DSA images were retrospectively evaluated by a neuroradiologist who had ten years of experience and was blinded to the results, to ensure that the initial DSA diagnoses were correct. The side and degree of subclavian stenosis of each patient were collected.

Carotid CTA Examination

Carotid CTA was performed on either a 320-detector CT scanner (Aquilion ONE, Toshiba, Japan) or a dual-source CT scanner (SOMATOM Force, Siemens, Germany). Scans were acquired in the caudal-cranial direction with coverage from the aortic arch to the vertebrobasilar junction after the administration of 45–55 mL of Ultravist 370 (Bayer, Germany) delivered at 4–5 mL/s followed by 30 mL of saline flush, using a bolus tracking technique with a trigger point set at 100 Hounsfield units (Aquilion ONE, Toshiba, Japan) or 120 Hounsfield units (SOMATOM Force, Siemens, Germany). CTA performed on the 320-detector scanner was obtained helically with the scanning parameters set as: tube voltage, 120 kV; tube current, 250 mA; slice thickness, 0.5 mm; reconstruction interval, 0.5 mm. CTA on the dual-source scanner was obtained in a dual-energy mode with the tube voltages set at 90 kV and 150 kV; tube current, 220 mA; slice thickness, 1 mm; and reconstruction interval, 0.7 mm. All the raw data were automatically reconstructed into cross-sectional images and transferred to a workstation for postprocessing. Maximum intensity projection (MIP), volume rendering (VR) and curved-planar reconstruction (CPR) images were routinely reconstructed, and multiplanar reconstruction was additionally applied where required. The degree of artery stenosis was measured according to the NASCET approach and graded using the same criteria as that in DSA. The CTA images were retrospectively reviewed for interpretation by the same neuroradiologist when CTA diagnosis disagreed with DSA diagnosis. The initial CTA diagnosis (including the side and degree of subclavian stenosis, and the diagnosis regarding VA), CTA characteristics of bilateral VA and model of CT scanner used in each patient were collected.

Statistical Analyses

Continuous variables were described as median (interquartile range) or mean ± standard deviation, whereas categorical variables were expressed as numbers and percentages. We used *t*-tests for comparison of normally distributed continuous variables, Mann-Whitney *U*-test for non-parametric variables, and Chi-squared test for categorical variables. The correlation between grade of SS and stenosis degree of SA was analyzed using Spearman's rank correlation. The diagnostic consistency between different imaging modalities was assessed using the Kappa test. A two-tailed $P<0.05$ was considered to be statistically significant. SPSS version 23.0 (IBM Corporation, USA) was used for all statistical analyses.

Results

Patient Characteristics

In total, 56 patients were diagnosed with SS using CDS, among which 23 underwent DSA, and the diagnosis of SS was confirmed. All these patients do not present significantly stenosis of VA ipsilateral to subclavian steno-occlusion. Four patients were excluded due to lack of CTA examinations, and 19 patients were finally included for further studies. The time interval between DSA and CDS examinations was 3–16 days (median, 8.0 [5.0–14.0]), and the time interval between CTA and CDS examinations was 0–11 days (median, 2.0 [0–4.0]). All patients had unilateral SS, with varying degrees of SA or IA stenosis proximal to the origin of ipsilateral VA. The demographic and clinical characteristics of the 19 patients are summarized in Table 1.

Grade of SS and Degree of SA Stenosis

On CDS, 8 patients had Grade 1 SS, 9 had Grade 2 SS and 2 had Grade 3 SS. The diameter of VA ipsilateral to subclavian steno-occlusion was 1.3–4.0 mm (3.1 ± 0.7 mm), and 2 patients had VA hypoplasia. The diameter of the contralateral VA was 2.6–4.8 mm (3.7 ± 0.6 mm). The degree of subclavian stenosis could not be determined due to the deep intrathoracic positions in 4 patients. Among the remaining 15 patients, severe stenosis was found in 3 patients, moderate stenosis in 10, and mild stenosis in 2 patients. These results were moderately consistent with the DSA results (Kappa = 0.545, $P = 0.002$).

On DSA, all patients presented steno-occlusion of SA or IA on the affected side, without steno-occlusion of the contralateral SA and bilateral VA. Among the 19 patients, 1 had IA lesion, 2 had both IA and SA lesions, and 16 had SA

Table 1 Demographic and Clinical Characteristics of the 19 Patients

Characteristics	Value
Age, years	74.1±7.6
Sex, n (%)	
Men	12 (63.2)
Women	7 (36.8)
Clinical presentation, n (%)	
Symptomatic	9 (47.4)
Asymptomatic	10 (52.6)
Side, n (%)	
Left	9 (47.4)
Right	10 (52.6)
Cause of subclavian artery stenosis	
Atherosclerosis	18 (94.7)
Subclavian artery web with dissection	1 (5.3)

lesions. Mild stenosis was found in 1 patient, moderate stenosis in 8, severe stenosis in 9, and occlusion in 1 patient. No significant correlation was observed between the grade of SS and the stenosis degree of SA or IA (P = 0.64).

CTA Manifestations

Among the 19 patients, 8 were examined using the Toshiba Aquilion ONE 320-detector CT scanner, the other 11 were investigated using the Siemens Somatom Force dual-source CT scanner. No significant differences were observed in the distributions of stenosis degree of SA or IA nor the grade of SS between patients examined using different CT scanners (P = 0.34 and 0.36, separately). None of the patients had significant abnormalities of the contralateral SA or VA on CTA.

Agreement Between CTA and DSA in the Stenosis Degree of SA or IA

The stenosis degree of SA or IA determined by initial CTA diagnosis was consistent with that assessed by DSA in 16 patients. In 1 of the remaining 3 patients, the stenosis degree of SA could not be determined due to the signal interference of metal denture. One patient with severe stenosis of aberrant right SA determined by DSA was misdiagnosed as mild stenotic right SA by CTA because the stenotic lesion was close to the aortic arch and obscured by adjacent arteries on MIP images, yet the cross-sectional and CPR images were not analyzed carefully. Another patient with moderate stenosis of right SA was misdiagnosed as mild stenotic right SA by CTA due to improper analysis of the CPR images at an inappropriate observation angle. The CTA diagnosis of SA stenosis degree in the latter 2 patients was corrected after retrospective review of the cross-sectional and CPR images by the neuroradiologist, which was consistent with the diagnosis of DSA. Overall, there was a high concordance between CTA and DSA in grading the stenosis degree of SA or IA (Kappa = 0.825, P = 0.000). The agreement analyses of CDS, DSA and CTA for grading stenosis of SA or IA are presented in Table 2.

CTA Manifestations of VA

There were 2 types of manifestations of VA ipsilateral to subclavian steno-occlusion on CTA: normal and shallow with or without a narrowed lumen. A 26.3% (5/19) of patients presented normal VA, whereas 73.7% (14/19) of patients presented shallow VA. Among these patients, 4 presented shallow imaging of proximal VA (V1 or V2 segment) and 10 presented shallow imaging of distal VA (V3 or V4 segment). A 28.6% (4/14) of patients with shallow VA were misdiagnosed as vertebral artery stenosis (2/4), vertebral artery occlusion (1/4) or vertebral artery dissection (1/4) at initial CTA diagnosis. The proportions of shallow VA in different stenosis degrees of SA or IA and grades of SS were presented in Tables 3 and 4, respectively. The incidence of shallow VA increased with higher SS grade as revealed by Table 4. The proportions of shallow VA in patients examined using the Toshiba Aquilion ONE 320-detector CT scanner

Table 2 Inter-Modality Agreements for Grading Stenosis of Subclavian Artery or Innominate Artery

Inter-Modality	Kappa Values	*P* value
CDS vs CTA	0.444	0.01
CDS vs DSA	0.545	0.002
CTA vs DSA	0.825	0.000

Abbreviations: CDS, carotid duplex sonography; CTA, computed tomography angiography; DSA, digital subtraction angiography.

Table 3 Degree of Stenosis of Subclavian Artery (SA) or Innominate Artery (IA) by DSA and Incidence of Shallow Vertebral Artery (VA)

Degree of Stenosis of SA or IA	n (%)	Shallow VA, n (%)
Mild stenosis	1 (5.0%)	1 (100%)
Moderate stenosis	8 (42.1%)	5 (62.5%)
Severe stenosis	9 (47.4%)	7 (77.8%)
Occlusion	1 (5.0%)	1 (100%)

Table 4 Grade of Subclavian Steal (SS) by CDS and Incidence of Shallow Vertebral Artery (VA)

Grade of SS	n (%)	Shallow VA, n (%)
Grade 1	8 (42.1%)	5 (62.5%)
Grade 2	9 (47.4%)	7 (77.8%)
Grade 3	2 (10.5%)	2 (100%)

and Siemens Somatom Force dual-source CT scanner were 87.5% and 63.6%, respectively. Univariate analysis revealed that the presence of shallow VA was not significantly associated with age, gender, grade of SS, stenosis degree of SA or IA, diameter of VA or model of CT scanner (all $P > 0.05$, Table 5).

Illustrative Cases

Patient 1, a 78-year-old woman had severe stenosis of right SA and Grade 2 SS. She was misdiagnosed as having subtotal occlusion of V3-V4 segments of right VA at initial CTA diagnosis, since carotid CTA revealed invisible V3 and V4 segments of the right VA on MIP images (Figure 1A) and shallow V3 segment on CPR images (Figure 1B). However, DSA demonstrated normal right VA (Figure 1C).

Table 5 Univariate Analysis of Associated Factors of Shallow Vertebral Artery (VA)

Associated Factors	Statistics	*P* value
Age[a]	−1.949	0.051
Gender[b]		1
Grade of SS[a]	−1.073	0.283
Stenosis degree of SA or IA[a]	−0.562	0.574
Diameter of VA[a]	−0.418	0.676
Model of CT scanner[b]		0.338

Notes: [a]Mann-Whitney *U*-test, [b]Chi-squared test.
Abbreviations: SS, subclavian steal; SA, subclavian artery; IA, innominate artery; CT, computed tomography.

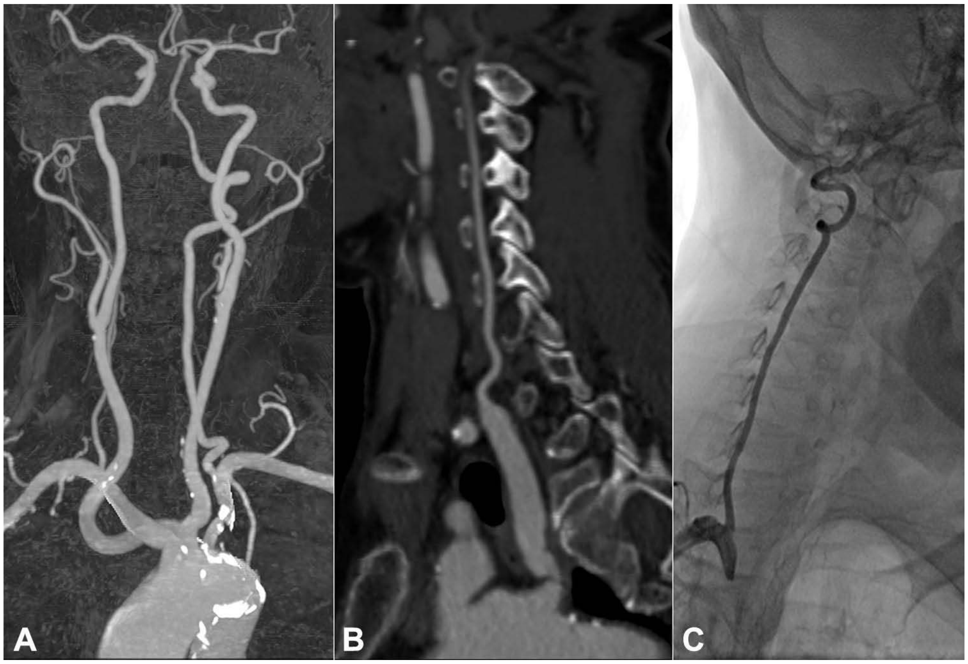

Figure 1 Patient 1: A 78-year-old woman with right subclavian steal was misdiagnosed as subtotal occlusion of intracranial right vertebral artery (VA) at initial CTA diagnosis. (**A**) The V3 and V4 segments of right VA was invisible on MIP images; (**B**) CPR images revealed severe stenosis of right subclavian artery and shallow V3 and V4 segments of right VA; (**C**) DSA demonstrated normal right VA.

Patient 2, a 78-year-old woman with severe stenosis of right SA and Grade 2 SS, presented shallow V1 and V2 segments of right VA on CTA. The V1 and V2 segments of the right VA were invisible on MIP images (Figure 2A) and found to be shallow on CPR images (Figure 2B).

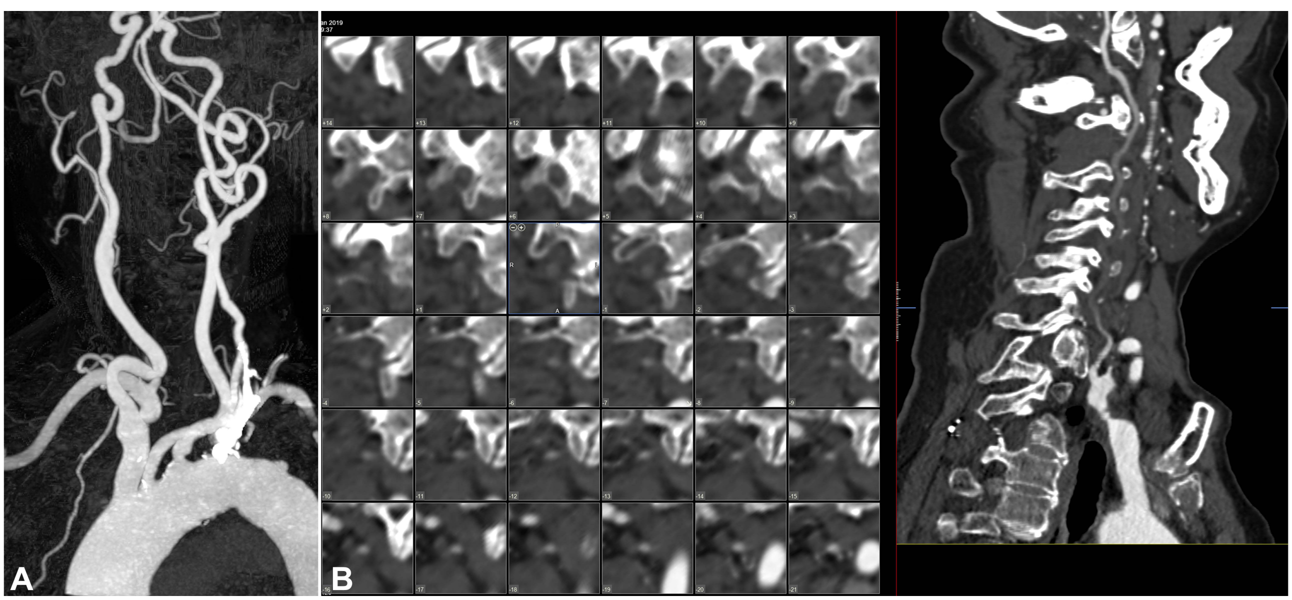

Figure 2 Patient 2: A 78-year-old woman with right subclavian steal presented shallow right vertebral artery (VA) on CTA. (**A**) The V1 and V2 segments of right VA was invisible on MIP images; (**B**) CPR images revealed severe stenosis of right subclavian artery and shallow V1 and V2 segments of right VA.

Discussion

SS is a hemodynamic phenomenon in which significant stenosis or occlusion of SA or IA results in a compromise of distal perfusion to ipsilateral VA. As the stenosis progresses, the pressure distal to the stenosis decreases, and a pressure gradient between bilateral VA gradually emerges, favoring reversed blood flow in the VA ipsilateral to subclavian steno-occlusion.[14] CDS is currently the first-line examination of SS due to its accessibility, non-invasiveness, inexpensiveness and advantages in investigating hemodynamic changes. However, it is limited in evaluating SA, IA and the origin of VA because of their intrathoracic locations. CTA confirms the presence and estimates the stenosis degree of SA or IA, and is commonly used in the diagnosis of SS.[9]

In this study, carotid CTA demonstrated a better agreement with DSA in diagnosing the stenosis degree of SA and IA than CDS, strengthening its diagnostic value for SS. However, certain limitations of CTA still exist in diagnosing artery stenosis. The severe calcification of vessel wall or high-density substance (aneurysm clip, hematoma, etc.) around the vessel will interfere with the display of vessel lumen, as was the case with unclear SA display due to the signal interference of metal denture in this study. Artificial limitations are also present. Ratanakorn et al[15] reported a patient with SS, in which DSA revealed complete occlusion at the origin of both SA, whereas CTA presented no evidence of SA stenosis. The false-negative CTA finding was attributed to inappropriate contrast administration technique and post-processing method. The misdiagnosis was corrected after retrospective reconstruction of the original data by the vascular radiologist. Fasen et al[16] investigated potential factors associated with diagnostic errors in evaluating large-vessel occlusion on CTA. They revealed that non-neuroradiologists were more likely to overlook large-vessel occlusion compared with neuroradiologists, indicating the importance of professional CTA interpreters in CTA diagnosis. In this study, the degree of SA stenosis in 2 patients was misjudged in initial CTA diagnosis because of uncareful interpretation of the images. The diagnoses were corrected after careful review of the cross-sectional and CPR images by the experienced neuroradiologist. Full recognition of the causes leading to diagnostic errors of CTA and avoiding them in clinical practice would improve the accuracy of CTA in diagnosing degree of SA stenosis.

To the best of our knowledge, this is the first report on abnormal CTA findings of VA ipsilateral to subclavian steno-occlusion in SS. In total, 73.7% of patients presented shallow VA, the incidences of which were not significantly different between patients examined by different CT scanners, suggesting that shallow VA is prevalent in SS, unaffected by the models of CT scanners and scanning parameters. The shallow VA imaging may be caused by uneven filling of contrast agent in the lumen of the affected VA due to abnormal hemodynamics in SS. Inability to differentiate flow direction is the inherent limitation of CTA. Although delayed phase imaging may help identify the retrograde filling of VA in SS,[17] it is not routinely used in neurovascular CTA. We speculate that the presence of shallow VA is related to the grade of SS, and the higher the grade of SS is, the more likely the shallow VA will appear. This speculation is supported by Table 3, which depicted that the incidence of shallow VA increased with the grade of SS. However, no significant correlation was found between shallow VA and the grade of SS, probably due to the small sample size. Thus, further studies with larger sample sizes are needed. Shallow VA may be an important clue of SS on CTA. On the other hand, extremely shallow VA on MIP and VR images may be misdiagnosed as vertebral arteriopathies, such as VA occlusion, thus misleading clinical decisions. Proper recognition of shallow VA ipsilateral to subclavian steno-occlusion in SS with careful analysis of various postprocessing images, especially cross-sectional and CPR images, combined with subclavian steno-occlusion and CDS findings, may help avoid misdiagnosis as vertebral arteriopathy and facilitate the accurate diagnosis of SS by CTA.

This study has several limitations. First, shallow VA was determined visually, which was subjective. The results' accuracy will be improved if the threshold of CT-value for identifying shallow VA is defined. Second, it is unclear whether shallow VA will occur in healthy people or other pathological conditions without setting a control group. The specificity of shallow VA for SS remains undetermined.

Conclusion

Carotid CTA is highly accurate for diagnosing subclavian steno-occlusion, which is the advantage of CTA in the diagnosis of SS. However, VA ipsilateral to subclavian steno-occlusion in SS may be shallow or even invisible, which is likely misdiagnosed as vertebral arteriopathy. Shallow VA is the pitfall of CTA in the diagnosis of SS, but it may be an important clue of SS on CTA. Proper recognition of shallow VA combined with subclavian steno-occlusion and CDS findings may help prevent misdiagnosis and assist in the correct diagnosis of SS by CTA.

Data Sharing Statement

Data is available from the corresponding author on reasonable request.

Ethics Approval and Informed Consent

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Second Affiliate Hospital of Chongqing Medical University (protocol code (2019)321 and date of approval 2019-7-21). Due to the retrospective nature of the study and the lowest risk to the research subjects, the informed consent application was waived. All patient data were anonymously recorded and securely protected to ensure patient confidentiality.

Acknowledgments

We thank Dr. Si-yao Chen for English editing, and Chongqing Nanan medical scientific research project for financial support.

Author Contributions

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agreed to be accountable for all aspects of the work.

Funding

This research was funded by Chongqing Nanan medical scientific research project, grant number 2019-04; and Chongqing medical scientific research project, grant number 2021MSXM296. The APC was funded by Chongqing Nanan medical scientific research project. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Disclosure

The authors declare no conflicts of interest in this work.

References

1. Ochoa VM, Yeghiazarians Y. Subclavian artery stenosis: a review for the vascular medicine practitioner. *Vasc Med*. 2011;16:29–34. doi:10.1177/1358863X10384174
2. Kargiotis O, Siahos S, Safouris A, Feleskouras A, Magoufis G, Tsivgoulis G. Subclavian steal syndrome with or without arterial stenosis: a review. *J Neuroimaging*. 2016;26:473–480. doi:10.1111/jon.12371
3. Shadman R, Criqui MH, Bundens WP, et al. Subclavian artery stenosis: prevalence, risk factors, and association with cardiovascular diseases. *J Am Coll Cardiol*. 2004;44:618–623. doi:10.1016/j.jacc.2004.04.044
4. Tan TY, Schminke U, Lien LM, Tegeler CH. Subclavian steal syndrome: can the blood pressure difference between arms predict the severity of steal? *J Neuroimaging*. 2002;12:131–135. doi:10.1111/j.1552-6569.2002.tb00109.x
5. Labropoulos N, Nandivada P, Bekelis K. Prevalence and impact of the subclavian steal syndrome. *Ann Surg*. 2010;252:166–170. doi:10.1097/SLA.0b013e3181e3375a
6. Bajko Z, Motataianu A, Stoian A, et al. Prevalence and clinical characteristics of subclavian steal phenomenon/syndrome in patients with acute ischemic stroke. *J Clin Med*. 2021;10:5237. doi:10.3390/jcm10225237
7. Chen SP, Hu YP, Fan LH, Zhu XL. Bidirectional flow in the vertebral artery is not always indicative of the subclavian steal phenomenon. *J Ultrasound Med*. 2013;32:1945–1950. doi:10.7863/ultra.32.11.1945
8. Chen SP, Hu YP, Fan LH, Guan LJ. Completely reversed flow in the vertebral artery does not always indicate subclavian steal phenomenon. *Ultrasound Med Biol*. 2014;40:1072–1082. doi:10.1016/j.ultrasmedbio.2013.12.004
9. Rafailidis V, Li X, Chryssogonidis I, et al. Multimodality imaging and endovascular treatment options of subclavian steal syndrome. *Can Assoc Radiol J*. 2018;69:493–507. doi:10.1016/j.carj.2018.08.003
10. Mousa AY, Morkous R, Broce M, et al. Validation of subclavian duplex velocity criteria to grade severity of subclavian artery stenosis. *J Vasc Surg*. 2017;65(6):1779–1785. doi:10.1016/j.jvs.2016.12.098

11. Yurdakul M, Tola M, Uslu OS. Color Doppler ultrasonography in occlusive diseases of the brachiocephalic and proximal subclavian arteries. *J Ultrasound Med*. 2008;27(7):1065–1070. doi:10.7863/jum.2008.27.7.1065
12. Hua Y, Jia L, Li L, Ling C, Miao Z, Jiao L. Evaluation of severe subclavian artery stenosis by color Doppler flow imaging. *Ultrasound Med Biol*. 2011;37(3):358–363. doi:10.1016/j.ultrasmedbio.2010.12.003
13. Barnett H, Taylor DW, Haynes RB, et al. Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. *N Engl J Med*. 1991;325:445–453.
14. Potter BJ, Pinto DS. Subclavian steal syndrome. *Circulation*. 2014;129:2320–2323. doi:10.1161/CIRCULATIONAHA.113.006653
15. Ratanakorn D, Laothamatas J, Pongpech S, Tirapanich W, Yamwong S. Pitfall of electron beam computed tomography angiography in diagnosis of subclavian steal syndrome. *J Neuroimaging*. 2002;12:80–83. doi:10.1111/j.1552-6569.2002.tb00098.x
16. Fasen B, Heijboer R, Hulsmans FH, Kwee RM. CT angiography in evaluating large-vessel occlusion in acute anterior circulation ischemic stroke: factors associated with diagnostic error in clinical practice. *AJNR Am J Neuroradiol*. 2020;41:607–611. doi:10.3174/ajnr.A6469
17. Bennett DL, Hamberg LM, Wang B, Hirsch JA, Gonzalez RG, Hunter GJ. Diagnostic yield of delayed phase imaging in CT angiography of the head and neck: a retrospective study. *PLoS One*. 2014;9:e99020. doi:10.1371/journal.pone.0099020