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ORIGINAL ARTICLE

CT cervico-cerebral angiography in acute stroke. Can we justify aortic arch imaging?

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Abstract

Objectives Computed tomography cervico-cerebral angiography (CTCCA) plays a pivotal role in the evaluation of acute stroke. Currently no evidence justifies the inclusion of the upper chest in the CTCCA field of view. The aim of this study was to assess the prevalence and clinical significance of vascular findings identified on CTCCA in the head, neck, and upper chest regions in patients presenting with acute stroke symptoms.

Methods A retrospective review of radiology images and reports of 900 consecutive patients (425 men, 475 women; mean age 63.2 years, age range 19–99 years) with a suspected acute stroke who underwent CTCCA in the emergency department between January 2011 and July 2016. Clinically significant vascular CTCCA findings were recorded for each patient within the head, neck, and upper chest regions, respectively.

Results Of the 900 patients, clinically significant vascular CTCCA findings were identified in 404/900 (44.8%) patients. 218/900 (24.2%) were located within the head region; 174/900 (19.3%) within the neck; and 12/900 (2.4%) in the upper chest. Of the 12 vascular findings located within the upper chest, 3/900 (0.33%) were related to a clinically significant posterior circulation infarct.

Conclusions Routine inclusion of the upper chest on CTCCA is currently difficult to justify in the evaluation of a suspected acute anterior circulation stroke, contributing significantly to total radiation dose without demonstrating significant extra-cranial vascular findings. Prospective studies adopting narrower fields of view excluding the upper chest are necessary.

Keywords Computed tomography angiography · Stroke

Introduction

Timely restoration of blood flow in acute ischemic stroke is key to reducing long-term morbidity and mortality [1]. Advances in computed tomography (CT) technology allow for accurate, rapid, and non-invasive evaluation of intracranial and extra-cranial vessels with CTCCA [2]. A noninvasive intracranial vascular study (for example computed tomography angiography) is strongly recommended by the American Heart Association/American Stroke Association in the evaluation of a suspected acute stroke if thrombolysis or mechanical thrombectomy is being considered (Class I, Level of Evidence A) [3]. With developments in endovascular techniques and recent positive randomized controlled studies showing the efficacy of endovascular therapy [4–8] in acute ischemic stroke, CTCCA is poised to play an increasingly pivotal role in the assessment of acute stroke. This increase in utilization of CT and the established link between malignancy and ionizing radiation exposure [9] is driving the need to optimize CT imaging protocols. For example, there has been a six-fold increase (from 0.5 mSv to 3.0 mSv) in the cumulative per-capita effective radiation dose from medical imaging in the USA from 1980 to 2006. [10].

The field of view (FOV) of a CTCCA stroke protocol extends from the aortic arch to the skull vertex. While the inclusion of the upper chest, aortic arch, and proximal extra-cranial vessels into the FOV may seem intuitive as a roadmap for interventional neuroradiologists [11–13], to our knowledge no evidence justifies this anatomical region's inclusion in the CTCCA field of view. In fact, due to the increased radiosensitivity of the structures [14, 15] incorporated into the chest region on a CTCCA study, the upper chest contributes significantly to the overall

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dose of the CTCCA study [16]. This study was designed to answer a question regarding the value of inclusion of the upper chest in the field of view of a CTCCA in a patient presenting with a suspected acute ischemic stroke.

Materials and methods

Patient selection

Institutional board review waived the need for ethical approval for this study. We included 900 consecutive adult patients who presented to the emergency department with acute stroke symptoms between January 1, 2011 and July 1, 2016, and underwent a non-contrast CT brain and CTCCA. All patients with a suspected acute stroke were reviewed by a vascular neurologist. Patients presenting with head trauma were excluded from the study. Age, sex, and intervention (thrombolysis or endovascular therapy) were recorded for each patient.

Image analysis

The radiology reports and CTCCA images were reviewed in all 900 patients. The radiology reports were reviewed and scored by senior radiology residents independently (GS and MOR). If there was uncertainty or discrepancy, the images were reviewed by a neuroradiologist with 15 years experience (EK) and a final decision is made. The degree of ICA stenosis was analyzed according to NASCET criteria using vessel analysis software on a dedicated TeraRecon workstation (Aquarius Intuition software; TeraRecon) that allowed 3D and reformatted images. The 1.0-mm axial source images were reconstructed using automated centerline extraction. The vessel of interest was selected using a single-click vessel trace on an axial imaging. Center-line tracings were generated and the region of maximal stenosis was chosen by visual inspection and evaluating the real-time calculations of minimum luminal diameter. The distal reference was chosen manually by visual inspection to allow the software to automatically calculate the percentage of vessel stenosis.

In consultation with a vascular neurologist, vascular findings in the head, neck, and chest regions of the CTCCA scan were classified as clinically significant if they were deemed to be directly related to the acute stroke presentation, i.e., if the stenosis or occlusion was ipsilateral and proximal to the acute ischemic territory. "Occlusion" was defined as the absence of contrast opacification of a vessel on initial acquisition [17]. For intracranial arteries, stenosis was defined using the Warfarin-Aspirin Symptomatic Intracranial Disease method (i.e., ≥ 50% caliber reduction) [18]. Clinically significantly, vascular findings were defined as (1) in the head: intracranial vessel stenosis or occlusion, acute ischemic change, intracranial aneurysm, neoplasm, acute hemorrhage, or other; (2) in the neck, > 50% stenosis of the internal carotid arteries, > 70% stenosis of the vertebral arteries, and carotid or vertebral artery vessel dissection or occlusion; and (3) in the chest, > 60% stenosis of the common carotid artery, > 70% stenosis of the vertebral artery, or common carotid or vertebral dissection/occlusion. Stratification of carotid stenosis was based on the North American Symptomatic Carotid Endarterectomy Trial guidelines [19]. The anatomical landmarks used to determine the head, neck, and chest regions of the CTCCA were adopted from a prior study (Fig. 1) [16]. The head region was defined from the skull vertex to the tip of the odontoid peg, the neck region from the tip of the odontoid peg to the C6–7 disc spaces, and the chest region from the C6 to C7 disc spaces to the aortic arch.

Imaging protocol

All CTA studies were performed using our standardized acute stroke protocol, which included a non-contrast CT (NCCT) brain followed immediately by a triple phase CTCCA. This study was performed using a 128-slice multidetector CT scanner (Siemens Medical Solutions, Erlangen, Germany) at 120 kV, 90 mAs (effective), collimation of 128 × 0.6 mm employing iterative reconstruction. The NCCT was performed from the base of the skull to the vertex. For the multiphase CTA [14, 20], the field of view (FOV) of the first phase extended from the aortic arch to skull vertex. Bolus tracking software was used with a trigger set on the descending aortic arch following administration of 80 ml of non-ionic intravenous contrast at 5 ml/s with a saline chaser of 40 ml at 6 ml/s. Image acquisition of the first phase was acquired with bolus tracking beginning after a 6-s delay. The FOV of the second

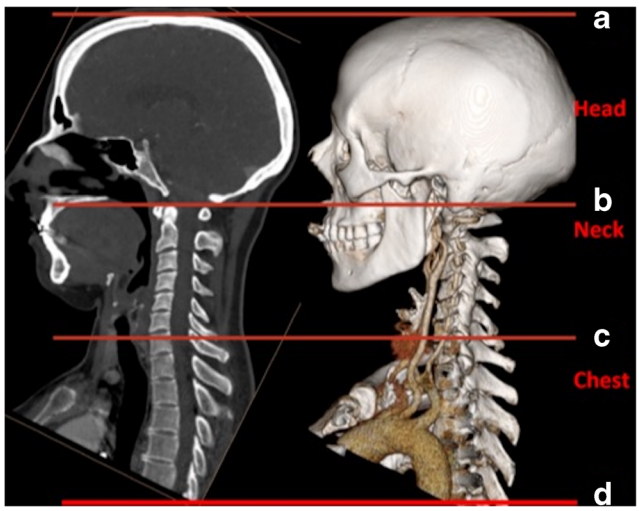

Fig. 1 Classification of the head, neck, and chest regions depicted using sagittal reformats and 3D reconstruction. The current conventional CTCCA field of view extends from the aortic arch to the skull vertex. The head region (**A**) extends from the skull vertex to the tip of the odontoid peg, the neck region (**B**) spans from the tip of the odontoid peg to the C6–7-disc spaces, and the chest region (**C**) extends from the C6 to C7 disc spaces to the aortic arch (**D**)

Table 1 CTCCA vascular findings within the upper chest, neck, and head regions

Location	Number of clinical significant CTA vascular findings	Correlates to acute stroke presentation
Overall	404/900 (44.8%)	245/900 (27.2%)
Upper chest	12/900 (2.4%)	3/12 (25%)
Neck	174/900 (19.3%)	55/174 (31.6%)
Head	218/900 (24.2%)	187/218 (85.8%)

and third phases spanned from the tip of the odontoid peg to the skull vertex performed with an 11- and 22-s time delay respectively. Axial images were reconstructed using a medium smooth algorithm and presented for review on angiographic windows with 1 mm slice thickness. In addition, axial, coronal, and sagittal three-dimensional MIP images were reconstructed with 30 mm slice thickness to aid visualization of the intracranial arterial system. Images were viewed on a dedicated picture archiving and communication system workstation.

Results

Nine-hundred consecutive patients were included in the study. There were 475 men and 425 women (mean age 63.2 years; median age 60, age range 19–99 years). 404/900 (44.8%) clinically significant vascular findings were identified within the head, neck, and chest regions (Table 1). Of these, 245/900 (27.2%) vascular findings were felt to be consistent with the patient's acute presentation.

In the head region on the NCCT and CTCCA, 24.2% of patients (218/900) had diagnostically significant vascular-related pathology (Table 2). In 85.8% of these patients (187/218), the radiological findings correlated with the patient's clinical presentation. 93/218 had an acute intracranial vessel occlusion (86 anterior circulation, 7 posterior circulation) and 64/218 patients had acute intracranial hemorrhage (39 subarachnoid, 19 intra-parenchymal, 6 subdural). "Other" intracranial pathology made up 9/900 findings, with five arteriovenous malformations (AVM), three brain tumors and one venous sinus thrombosis identified. The remaining 31/218 (14.2%) patients demonstrated incidental unruptured intracranial aneurysms, which did not correlate with clinical presentation.

In the neck portion of the CTCCA, clinically significant vascular pathology was identified in 19.3% of cases (174/900) (Table 3). Of these, 66.1% (115/174) had a > 50% internal carotid artery stenosis, 42.5% (41/174) had total internal carotid artery occlusion, and 10.3% (18/174) had internal carotid or vertebral artery dissections. Of the 174 cases with clinically significant vascular pathology within the neck portion of the study, vascular findings in 55 cases (31.6%) were felt to account for the patients' acute clinical presentation.

In the upper chest, clinically relevant vascular pathology (Table 4) was identified in 3/900 (0.33%), all of which demonstrated occlusion from the origin of the vertebral artery segment V1.

Discussion

CTA has now established itself as an accurate, accessible, and non-invasive tool for assessing intra- and extra-cranial vessels [21]. Intracranial vessels can be evaluated for the location, size, and extent of the thrombus [22, 23]. For these reasons, all recent clinical trials [4–8] employed a CTA technique. The introduction of multiphase CTA now allows for assessment of collateral vessels [24] and aids the detection of intracranial anterior circulation occlusions [25]. Therefore, in conjunction with the recent DAWN [26] and DIFUSE 3 [27] studies demonstrating the benefit of delayed endovascular therapy up to 24 h from time of onset of symptoms, continued expansion in the use of CTA in the acute stroke setting can be expected.

Table 2 CTCCA vascular findings in the head region

Findings	Number	Correlates to acute stroke presentation
Acute ischemic change with no vessel occlusion/stenosis	21/900 (2.3%)	21/21 (100%)
Stenosis or occluded intracranial vessel	93/900 (10.3%)	93/93 (100%)
Incidental intracranial aneurysm	31/900 (3.4%)	0/31 (0%)
Acute hemorrhage	64/900 (7.1%)	64/64 (100%)
Other	9/900 (1%)	8/8 (100%)
Total	218/900 (24.2%)	187/218 (85.8%)

Table 3 CTCCA vascular findings in the neck region

Findings	Number	Correlates to acute stroke presentation
50–70% internal carotid artery stenosis	67/900 (7.4%)	3/67 (4.5%)
> 70% internal carotid artery stenosis	48/900 (5.3%)	6/48 (12.5%)
ICA dissection	6/900 (0.7%)	6/6 (100%)
Total occlusion of the internal carotid artery	41/900 (4.6%)	29/41 (70.7%)
Vertebral artery dissection	12/900 (1.3%)	11/12 (91.7%)
Total	174/900 (19.3%)	55/174 (31.6%)

The field of view (FOV) of the CTCCA currently extends from the upper chest to the skull vertex (Fig. 1). Although the upper chest is routinely included in CTCCA stroke protocol, we have demonstrated that the incidence of clinically significant vascular findings within the upper chest region, defined as the region from the level of the aortic arch to the C6–C7 disc spaces, is only 3/900 (0.33%) (Tables 1 and 4). The low incidence of significant vascular findings comes at the expense of the upper chest portion receiving a significant proportion of the effective dose due to the high radiosensitivity of the lungs. The low incidence of significant vascular findings is consistent with another recent study [16] and further questions the added value of the upper chest on CTCCA in patients presenting a suspected acute stroke. Although calculation of patient dose was beyond the scope of this study, several well-constructed studies have performed dose estimates for CTCCA [14–16]. The calculated mean estimated effective dose for a single phase CTCCA is approximately 5 mSv, and when combined with two further intracranial phases ("triple phase CTA") the dose is approximately 6 mSv (Fig. 2). These dose estimates, although serving as a useful guide, should be cautiously interpreted due to heterogeneity of CT vendors, scan parameters, and patient demographics. Despite this heterogeneity, limiting the FOV of a CTCCA to exclude the upper chest can reduce overall patient dose by as much as 53% using a single phase CTCCA protocol, albeit with a triple phase protocol a more modest reduction in dose can be expected [16]. Of note, all three patients with clinically significant vascular findings in the upper chest presented with posterior circulation stroke symptoms, and their respective CTCCA findings demonstrated extra-cranial vertebral artery dissection involving the V1 vertebral artery segment. Although the V1 segment is the least common site for vertebral artery dissection [28], we recommend employing the conventional CTCCA FOV from arch to vertex (Fig. 1) for a suspected posterior circulation infarct for complete visualization of the vertebral arteries.

We do acknowledge that CTCCA of the upper chest allows for analysis of the aortic arch and great vessels; this may assist interventional neuroradiologists with catheter selection, and predict technical difficulty and procedural failure [29–32] in a time-critical procedure. However, it should be noted that up to 40% of patients with an acute stroke will have a LVO amenable to thrombectomy if imaging is performed within 6 h [33]. Identifying these patients prior to CTCCA remains challenging. Patients presenting with acute suspected stroke with a severe clinical syndrome, for example, have a higher pre-test probability for an intracranial vessel occlusion [34–36]. In this setting, knowledge of the aortic arch and proximal great vessels might have a bearing on technical considerations at thrombectomy, and addition of the upper chest in the CT angiography may be warranted.

While other studies have advocated for increasing the CTA FOV in the assessment of an acute ischemic stroke [37], we propose a narrower FOV to extend from just below the carotid bifurcation at the level of the C6–C7 disc spaces to the skull vertex (Fig. 3). This takes into account the significant variation of the level of the carotid bifurcation [38, 39], which is located between C3 and C5 in the majority (133/140, 95%) [40] of patients. This reduced FOV will allow for complete evaluation of the carotid bifurcation and can be easily identified on the lateral topogram by counting down from the C1 posterior arch. If this reduced FOV was applied to our patient cohort with a suspected acute anterior circulation infarct, no significant vascular findings would have been missed.

Table 4 CTCCA vascular findings in the upper chest region

Findings	Number	Related to acute stroke presentation
Vertebral artery occluded from its origin (V1 segment)	9	3/9 (33.3%)
Thrombus in innominate artery and right common carotid artery	1	0/1(0%)
70% proximal subclavian artery stenosis	1	0/1 (0%)
Thoracic aneurysm 4.8 cm	1	0/1 (0%)

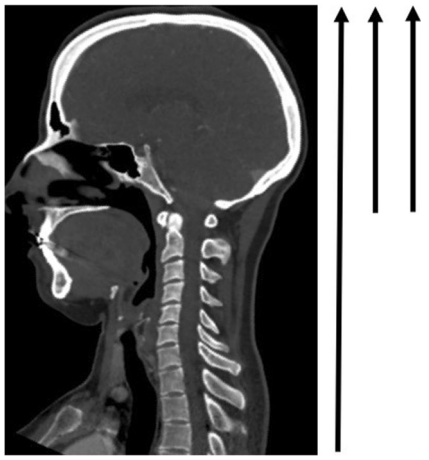

Fig. 2 Multiphase CT angiography image outlining the FOV of each of the sequential three phases. The first phase (long arrow) extends from the aortic arch to skull vertex. The next two phases (short arrows) extend from the tip of the odontoid peg to the skull vertex and are performed with an 11- and 22-s time delay respectively

Limitations of our study include its uncontrolled, single center, and retrospective nature. Furthermore, patients who had a suspected stroke and did not have a NCCT and/or CTCCA were not included in our study. CTA of the head and neck vessels was only analyzed in the arterial phase and not correlated with findings on other angiographic or sonographic methods. In addition, we did not capture all patients presenting to our institution with acute stroke, as patients with imaging performed at outside institutions or patients who only had a NCCT brain or magnetic resonance brain imaging brain were not included for analysis. Finally, as the primary aim of the study was the assessment of significant vascular findings in patients undergoing a CTCCA for a suspected acute stroke, we did not calculate patient dose or quantify dose reduction that could be achieved with exclusion of the upper chest regions within our cohort. Further studies with a focus on dose reduction that employ modern scanning technology and dose reduction technique are required, given the rapid rise in the utilization of CTA imaging in the acute stroke setting.

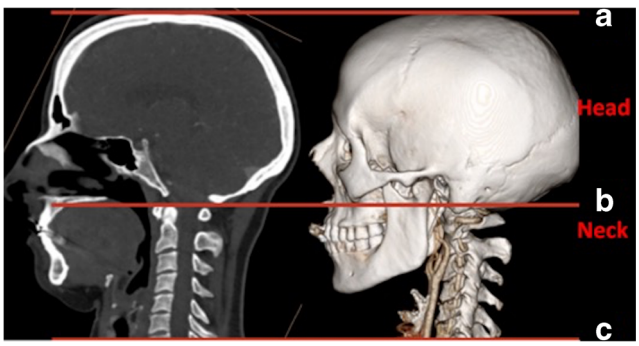

Fig. 3 Proposed reduced CTCCA field of view in sagittal reformat and 3D reconstruction. The lower limit of the FOV now extends from the C6 to C7 disc spaces to the skull vertex, previously extending from the aortic arch to skull vertex

Conclusion

With the huge increase in utilization of CTCCA in acute stroke, inclusion of the upper chest on CTCCA must be debated. In a suspected acute anterior circulation stroke, there is limited evidence for including the upper chest on CTCCA, with this study identifying no clinically significant vascular findings at the expense of a substantial additional radiation exposure. We propose that a limited CTCCA FOV from the C6 to C7 intervertebral disc spaces to skull vertex may allow for optimal evaluation of the significant intra and extracranial vascular structures while minimizing radiation dose. Prospective studies utilizing a narrowed FOV in the acute stoke setting are required.

Compliance with ethical standards

Ethical disclosures None.

References

1. Powers WJ, Derdeyn CP, Biller J et al (2015) American Heart Association/American Stroke Association focused update of the 2013 guidelines for the early management of patients with acute ischemic stroke regarding endovascular treatment. Stroke 46(10): 3020–3035
2. Esteban JM, Cervera V (2004) Perfusion CT and angio CT in the assessment of acute stroke. Neuroradiology 46(9):705–715
3. Jauch EC, Saver JL, Adams HP et al (2013) Guidelines for the early management of patients with acute ischemic stroke. Stroke 44(3): 870–947
4. Jovin TG, Chamorro A, Cobo E et al (2015) Thrombectomy within 8 hours after symptom onset in ischemic stroke. N Engl J Med 372(24):2296–2306
5. Saver JL, Goyal M, Bonafe A et al (2015) Stent-retriever thrombectomy after intravenous t-PA vs. t-PA alone in stroke. N Engl J Med 372(24):2285–2295
6. Campbell BC, Mitchell PJ, Kleinig TJ et al (2015) Endovascular therapy for ischemic stroke with perfusion-imaging selection. N Engl J Med 372(11):1009–1018
7. Goyal M, Demchuk AM, Menon BK et al (2015) Randomized assessment of rapid endovascular treatment of ischemic stroke. N Engl J Med 372(11):1019–1030
8. Berkhemer OA, Fransen PS, Beumer D et al (2015) A randomized trial of intraarterial treatment for acute ischemic stroke. N Engl J Med 2015(372):11–20
9. Smith-Bindman R, Lipson J, Marcus R et al (2009) Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch Intern Med 169(22):2078–2086
10. Mettler FA Jr, Wiest PW, Locken JA, Kelsey CA (2000) CT scanning: patterns of use and dose. J Radiol Prot 20(4):353–359
11. Almandoz JE, Romero JM, Pomerantz SR et al (2010) Computed tomography angiography of the carotid and cerebral circulation. Radiol Clin N Am 48(2):265–281
12. Goyal M, Menon BK, Hill MD et al (2014) Consistently Achieving computed tomography to endovascular recanalization <90 Minutes. Stroke 45(12):e252–e256

13. Menon BK, Campbell BC, Levi C et al (2015) Role of imaging in current acute ischemic stroke workflow for endovascular therapy. Stroke STROKEAHA-115
14. Menon BK, d'Esterre CD, Qazi EM et al (2015) Multiphase CT angiography: a new tool for the imaging triage of patients with acute ischemic stroke. Radiology 275(2):510–520
15. Yamauchi-Kawara C, Fujii K, Aoyama T, Yamauchi M, Koyama S (2010) Radiation dose evaluation in multidetector-row CT imaging for acute stroke with an anthropomorphic phantom. Br J Radiol 83(996):1029–1041
16. Deipolyi AR, Hamberg LM, Gonzaléz RG et al (2015) Diagnostic yield of emergency department arch-to-vertex CT angiography in patients with suspected acute stroke. Am J Neuroradiol 36(2):265–268
17. Vanacker P, Lambrou D, Eskandari A, Maeder P, Meuli R, Ntaios G, Michel P (2014) Improving prediction of recanalization in acute large-vessel occlusive stroke. J Thromb Haemost 12:814–821. https://doi.org/10.1111/jth.12561
18. Chimowitz MI, Lynn MJ, Howlett-Smith H, Stern BJ, Hertzberg VS, Frankel MR, Levine SR, Chaturvedi S, Kasner SE, Benesch CG, Sila CA, Jovin TG, Romano JG, Warfarin-Aspirin Symptomatic Intracranial Disease Trial Investigators (2005) Warfarin-aspirin symptomatic intracranial disease trial investigators. Comparison of warfarin and aspirin for symptomatic intracranial arterial stenosis. N Engl J Med 352:1305–1316. https://doi.org/10.1056/NEJMoa043033
19. Chang YJ, Golby AJ, Albers GW (1995) Detection of carotid stenosis. Stroke 26(8):1325–1328
20. Demchuk AM, Menon BK, Goyal M (2016) Comparing vessel imaging. Stroke 47(1):273–281
21. Menon BK, Demchuk AM (2011) Computed tomography angiography in the assessment of patients with stroke/TIA. Neurohospitalist 1(4):187–199
22. Maas MB, Lev MH, Ay H et al (2009) Collateral vessels on CT angiography predict outcome in acute ischemic stroke. Stroke 40(9):3001–3005
23. Knauth M, von Kummer R, Jansen O et al (1997) Potential of CT angiography in acute ischemic stroke. Am J Neuroradiol 18(6): 1001–1010
24. Amy YX, Zerna C, Assis Z, Holodinsky JK et al (2016) Multiphase CT angiography increases detection of anterior circulation intracranial occlusion. Neurology 87(6):609–616
25. Volny O, Cimflova P, Kadlecova P et al (2017) Single-phase versus multiphase CT angiography in middle cerebral artery clot detection—benefits for less experienced radiologists and neurologists. J Stroke Cerebrovasc Dis 26(1):19–24
26. Nogueira RG, Jadhav AP, Haussen DC, Bonafe A, Budzik RF, Bhuva P, Yavagal DR, Ribo M, Cognard C, Hanel RA, Sila CA (2018) Thrombectomy 6 to 24 hours after stroke with a mismatch between deficit and infarct. N Engl J Med 378(1):11–21
27. Albers GW, Marks MP, Kemp S, Christensen S, Tsai JP, Ortega-Gutierrez S, McTaggart RA, Torbey MT, Kim-Tenser M, Leslie-Mazwi T, Sarraj A (2018 Feb 22) Thrombectomy for stroke at 6 to 16 hours with selection by perfusion imaging. N Engl J Med 378(8):708–718
28. Shin JH, Suh DC, Choi CG, Lee HK (2000) Vertebral artery dissection: spectrum of imaging findings with emphasis on angiography and correlation with clinical presentation. RadioGraphics 20: 1687–1696
29. Macdonald S, Lee R, Williams R et al (2009) Towards safer carotid artery stenting. Stroke 40(5):1698–1703
30. Faggioli G, Ferri M, Rapezzi C et al (2009) Atherosclerotic aortic lesions increase the risk of cerebral embolism during carotid stenting in patients with complex aortic arch anatomy. J Vasc Surg 49(1):80–85
31. Faggioli G, Ferri M, Gargiulo M et al (2007) Measurement and impact of proximal and distal tortuosity in carotid stenting procedures. J Vasc Surg 46(6):1119–1124
32. Faggioli GL, Ferri M, Freyrie A et al (2007) Aortic arch anomalies are associated with increased risk of neurological events in carotid stent procedures. Eur J Vasc Endovasc Surg 33(4):436–441
33. Heldner MR, Hsieh K, Broeg-Morvay A et al (2016) Clinical prediction of large vessel occlusion in anterior circulation stroke: mission impossible? J Neurol 263(8):1633–1640
34. Cooray C, Fekete K, Mikulik R et al (2015) Threshold for NIH stroke scale in predicting vessel occlusion and functional outcome after stroke thrombolysis. Int J Stroke 10(6):822–829
35. Vanacker P, Heldner MR, Amiguet M, Faouzi M, Cras P, Ntaios G, Arnold M, Mattle HP, Gralla J, Fischer U, Michel P (2016) Prediction of large vessel occlusions in acute stroke: National Institute of Health Stroke Scale is hard to beat. Crit Care Med 44(6):e336–e343
36. de la Ossa NP, Carrera D, Gorchs M et al (2014) Design and validation of a prehospital stroke scale to predict large arterial occlusion. Stroke 45(1):87–91
37. Boussel L, Cakmak S, Wintermark M, Nighoghossian N, Loffroy R, Coulon P, Derex L, Cho TH, Douek PC (2011) Ischemic stroke: etiologic work-up with multidetector CT of heart and extra-and intracranial arteries. Radiology 258(1):206–212
38. Hayashi N, Ohtani Y, Ohtani O et al (2005) Surgical anatomy of the cervical carotid artery for carotid endarterectomy. Neurol Med Chir 45(1):25–30
39. Michalinos A, Chatzimarkos M, Arkadopoulos N et al (2016) Anatomical considerations on surgical anatomy of the carotid bifurcation. Anat Res Int 7:2016
40. McNamara JR, Fulton GJ, Manning BJ (2015) Three-dimensional computed tomographic reconstruction of the carotid artery: identifying high bifurcation. Eur J Vasc Endovasc Surg 49(2):147–153