Yang Tang

Atlas of Emergency Neurovascular Imaging

Springer

Atlas of Emergency Neurovascular Imaging

Yang Tang

Atlas of Emergency Neurovascular Imaging

Springer

Yang Tang
Department of Radiology
Virginia Commonwealth University Health System
Richmond, VA
USA

ISBN 978-3-030-43653-7 ISBN 978-3-030-43654-4 (eBook)
https://doi.org/10.1007/978-3-030-43654-4

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

To my beloved family for their patience and support and to all the patients I have the privilege to serve.

Preface

Ischemic stroke and hemorrhage are commonly encountered in the emergency setting and are among the leading causes of morbidity and mortality worldwide. Imaging plays a central role in diagnosing and triaging these patients. The emergent utilization of computed tomography (CT) and magnetic resonance imaging (MRI)-based neurovascular imaging has increased tremendously in the recent years, mostly driven by the advance of endovascular stroke intervention and the need of screening severe trauma patients for blunt cerebrovascular injury. Neurovascular imaging has become a key element in the training and clinical practice of neuroradiologists, emergency radiologists, neurointerventionalists, stroke neurologists, and neurosurgeons.

This book aims to provide a concise but comprehensive review of the entire spectrum of emergent neurovascular imaging, with emphasis on noninvasive CT angiography (CTA), MR angiography (MRA), and perfusion techniques. It is organized into 11 chapters. The first three chapters address the topics of acute stroke imaging, including algorithms based on recent clinical trials and updated American Heart Association stroke guideline, vascular territories, and stroke mimics. These are followed by discussions of cerebral venous thrombosis, vasculopathies, aneurysms, and vascular malformations. The remaining chapters are devoted to the traumatic neurovascular injury, as well as the relatively rare albeit important topics of head and neck vascular emergencies and spinal vascular diseases. The book has an image-rich format, including more than 280 selected CT, MRI, or digital subtraction angiography (DSA) images. The readers can use the book either as a primary learning tool or a quick reference guide.

I would like to thank my colleagues at Virginia Commonwealth University for their contributions, as well as the editorial staff at Springer for inspiring me and making this book possible.

Richmond, VA, USA — Yang Tang, MD, PhD

Contents

Contributors

Xinli Du, MD, PhD Department of Neurology, Virginia Commonwealth University Health System and Hunter Homes McGuire Veterans Affair Medical Center, Richmond, VA, USA

Seyed Mohammad Gharavi, MD Department of Radiology, Virginia Commonwealth University Health System, Richmond, VA, USA

Christopher Ovanez, MD, MPH, MS Department of Radiology, Virginia Commonwealth University Health System, Richmond, VA, USA

Yang Tang, MD, PhD Department of Radiology, Virginia Commonwealth University Health System, Richmond, VA, USA

Acute Stroke Imaging

1

Yang Tang

1.1 Introduction

Acute ischemic stroke (AIS) is commonly due to cardioembolism, large vessel atherosclerosis, or lacunar infarctions. Other rare etiologies including dissection, vasculopathy, and cerebrovenous thrombosis will be discussed in other chapters. Anterior circulation large vessel occlusion (LVO) involving the intracranial ICA and middle cerebral artery (MCA) M1 segment is a very common stroke subtype and is associated with significant morbidity and mortality.

There has been a major paradigm shift in the AIS treatment in the past several years. Until 2015, intravenous administration of tissue plasminogen activator (IV tPA) has been the mainstay of treatment, which can be given up to 4.5 hours after symptom onset [1]. In 2015, a total of six randomized clinical trials established the significant benefit of emergent endovascular treatment (EVT) in treating patients with anterior circulation LVO within 6 hours of symptom onset compared to the best medical treatment [2–7]. In 2018, two late-window trials including DAWN [8] and DEFUSE 3 [9] have demonstrated similarly overwhelming benefit of EVT, leading to new guidelines that recommend endovascular treatment of anterior circulation LVO up to 24 hours of stroke onset or last known well [10]. Most recently, investigators have been able to extend the IV tPA treatment window from 4.5 to 9 hours in patients with salvageable tissue identified by CT perfusion or DWI/MR perfusion [11] and in patients of unknown stroke onset with DWI/FLAIR mismatch on MRI [12]. Advanced neuroimaging plays a critical role in triaging patients for endovascular and thrombolytic treatments, and its application has continued to evolve.

1.2 Core, Penumbra, and Oligemia

The concepts of ischemic core and penumbra are essential to understanding the current role of acute stroke imaging and intervention.

In cases of LVO, the brain tissue in close proximity to the occluded vessel undergoing irreversible cell death regardless of subsequent reperfusion status is defined as the infarction "core."

The functionally impaired yet still viable and salvageable tissue surrounding the core is commonly termed as "penumbra" or "tissue at risk." The penumbra will progress to infarction if timely reperfusion does not occur. The fate of penumbra largely depends on the quality of pial collateral flow and on the severity/duration of ischemia.

Further away from the ischemic core, there is tissue of "benign oligemia," which is hypoperfused yet functionally intact due to adequate collateral flow. This tissue will survive even if reperfusion does not occur. It is important to distinguish benign oligemia from true penumbra to avoid the overestimation of tissue at risk, although this is frequently difficult on perfusion imaging, especially in cases complicated by underlying chronic vascular stenosis.

1.3 Goal of Acute Stroke Imaging

The goal of acute stroke imaging includes:

1. Exclude acute intracranial hemorrhage.
2. Evaluate the patency of intracranial and cervical vasculature.
3. Assess the quality of collateral circulation in cases of LVO.
4. Estimate the volume of core infarct and penumbra.

Both CT- and MRI-based techniques have been used to achieve the above goals. The currently recommended imaging algorithm varies for patients who present within the early window (<6 hours from symptom onset or last known well) and late window (6–24 hours from symptom onset or last known well).

For early-window patients, non-contrast CT (NCCT) and CT angiography (CTA) can usually provide sufficient

Y. Tang, *Atlas of Emergency Neurovascular Imaging*, https://doi.org/10.1007/978-3-030-43654-4_1

information for EVT selection. Patients with anterior circulation LVO and absence of a large infarction on NCCT are considered safe candidates for EVT. Perfusion imaging may not be necessary in these patients, as it can potentially cause delay of treatment and inappropriate exclusion of patients who may otherwise benefit from EVT [13].

For late-window patients with anterior circulation LVO confirmed by vascular imaging, a perfusion study, either CT perfusion (CTP) or MRI with diffusion-weighted imaging (DWI) with or without MR perfusion (MRP), is recommended to select the subgroup of patients meeting the eligibility criteria of DAWN and DEFUSE 3 [13].

1.4 CT-Based Imaging

Owing to its widespread availability and rapid acquisition, CT is the modality of choice in the vast majority of stroke centers. A multimodal stroke CT consists of NCCT, CTA, and CTP, which can be performed within a few minutes by current multidetector scanners.

1.4.1 NCCT

NCCT is typically the first imaging modality performed to exclude intracranial hemorrhage, as well as other acute pathologies such as mass or hydrocephalus that can mimic AIS clinically. It is recommended that initial brain imaging should be performed within 20 minutes of arrival in the emergency department in at least 50% of patients who may be candidates for thrombolysis or thrombectomy [14].

Initial interpretation can be made on the CT console to facilitate the clinical decision-making regarding IV tPA. Axial, coronal, and sagittal reconstructed images should be carefully reviewed on the PACS workstation immediately afterward. Subtle hemorrhages can be missed on the axial images and more easily detectable on the sagittal and coronal reformations (Fig. 1.1).

Although not sensitive, NCCT can detect early ischemic changes including subtle loss of gray–white matter differentiation, sulcal effacement, parenchymal hypodensity, or hyperdense vessels.

Loss of gray–white differentiation is the hallmark of acute infarction at NCCT. Special attention should be directed to insula and basal ganglia, which are most commonly affected by MCA occlusion (Fig. 1.2). It is helpful to use a narrow "stroke window" on PACS station to detect early ischemia. Hypodensity > 1/3 of MCA territory used to be considered as a relative contraindication for IV tPA, although the recent guideline states that the extent and severity of acute hypoattenuation or early ischemic changes should not be used as a criterion to withhold therapy due to insufficient evidence [14].

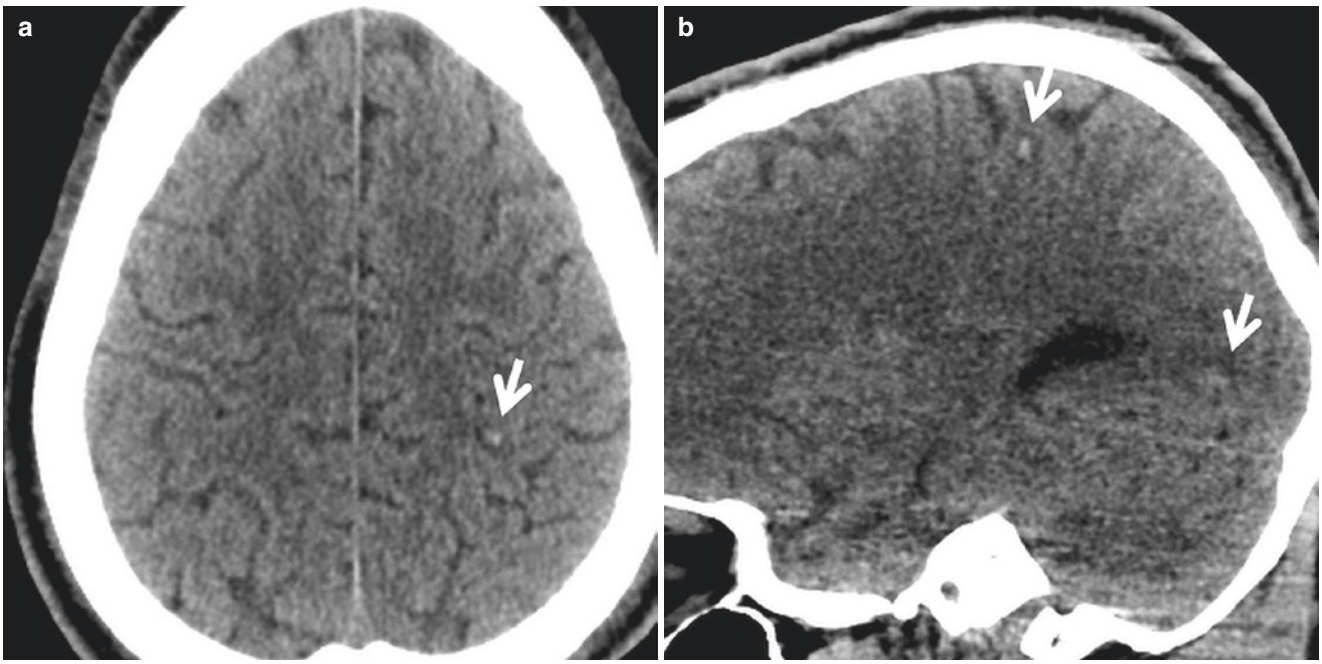

Fig. 1.1 Subtle intracranial hemorrhage in NCCT for patients with stroke alert. (**a** and **b**), Axial and sagittal CT demonstrate a small focus on intraparenchymal hemorrhage in the left parietal lobe (*arrow*). An additional focus of hemorrhage is seen in the left occipital lobe on the sagittal image (*arrow*). (**c** and **d**), Axial and coronal CT show sulcal subarachnoid hemorrhage in the right occipital lobe (*arrow*). (**e** and **f**), Axial and coronal CT demonstrate small amount of subdural hemorrhage along the right cerebral convexity, nearly isodense to the brain parenchyma. It is critical to evaluate the NCCT for subtle hemorrhage in stroke patient before administering tPA

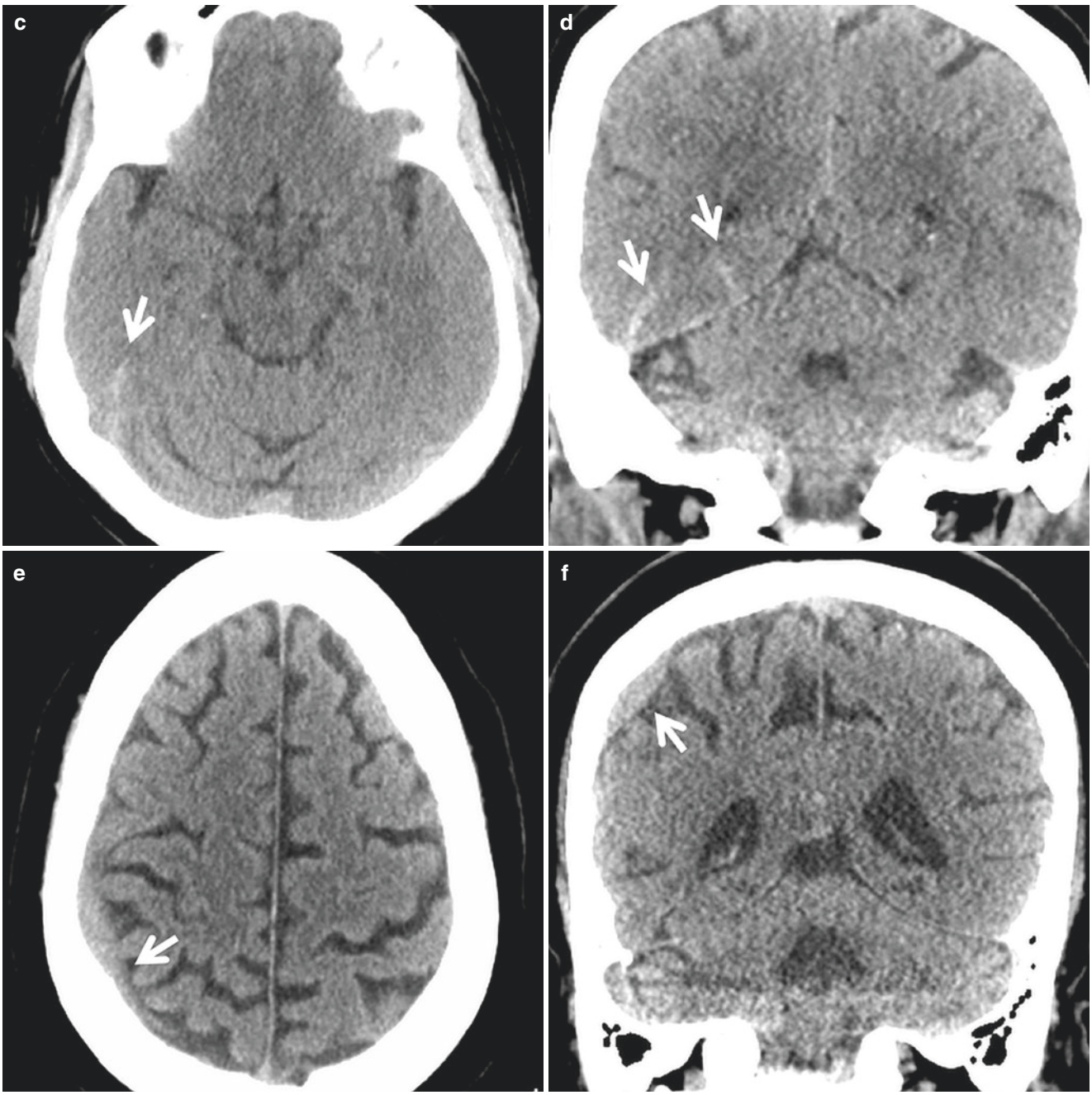

Fig. 1.1 (continued)

The hyperdense vessel sign corresponds to acute luminal thrombosis, which can be seen in intracranial ICA, MCA, ACA, and vertebral and basilar artery. A hyperdense MCA > 8 mm in length is an indicator that IV tPA alone is unlikely to achieve successful recanalization although this should not be used as a criterion to withhold IV tPA from patients who otherwise qualify [14].

Alberta Stroke Program Early CT Score (ASPECTS) has been developed as a system to quantify the early ischemic changes from MCA stroke (http://www.aspectsinstroke.com). The MCA territory is divided into 10 segments at ganglionic and supraganglionic levels [15]. With a score of 10 indicating a normal CT, the score is decreased by 1 point for each segment of the brain affected by ischemic change. Patients with ASPECTS of 7 or less have been shown to have poor outcome [16]. Despite its successful application in several clinical trials, ASPECTS has only moderate interobserver reliability even among the experienced neuroradiologists, which limits its routine use in EVT selection [17]. A recent study showed that ASPECTS by using automated software had better agreement than did experienced neuroradiologists [18].

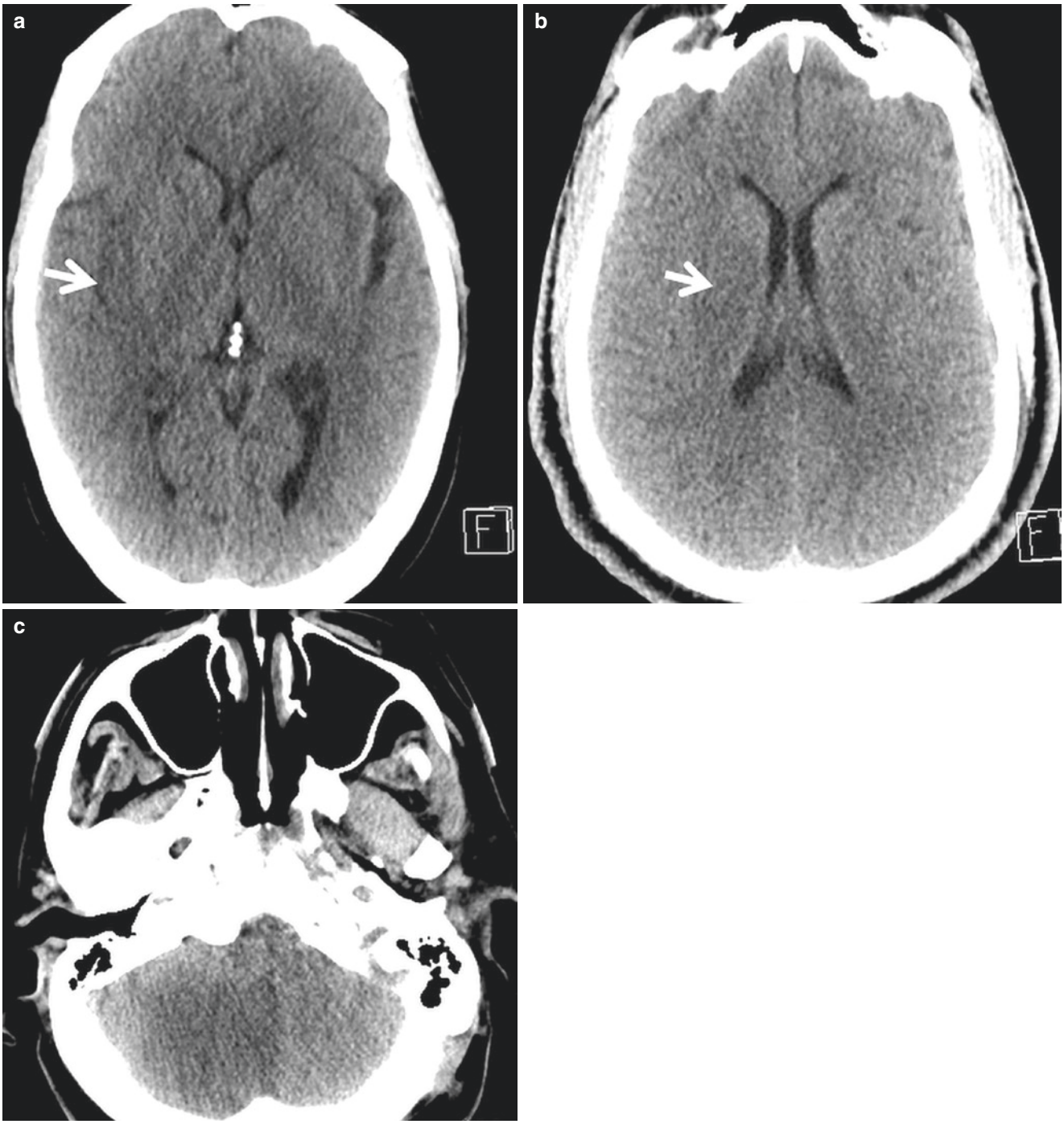

Fig. 1.2 CT findings of acute ischemic stroke. (**a**), NCCT shows loss of gray–white matter differentiation of right insula. (**b**), NCCT in a different stroke patient shows hypodensity in the right lentiform nucleus. (**c**), NCCT shows hypodensity of right cerebellum

1.4.2 CT Angiography

CTA from arch to vertex is the preferred modality to evaluate intracranial and cervical large vessel occlusion. In addition, CTA can provide useful information for EVT planning, such as variant anatomy of the aortic arch, tortuosity of supra-aortic branches, and extracranial vascular stenoses, occlusions, and dissections.

CTA should be performed immediately after NCCT without removing the patient from the scanner. Administration of iodinated contrast without first testing renal function in AIS patients without known history of renal impairment is an

accepted practice, as the benefit of salvaging brain from potentially devastating ischemic injury outweighs the risk of contrast-induced nephropathy [19]. It should be noted that performing CTA should not delay the administration of IV tPA. If NCCT is negative for acute hemorrhage and the patient has no other contraindications, tPA should be reconstituted and given as a parallel process to the CTA.

CTA source data should be immediately post-processed into thick slab (typically 30 mm slice thickness with 5 mm overlapping interval) axial, coronal, and sagittal maximum intensity projection (MIP) images to facilitate the identification of LVO. Coronal images are best to evaluate ICA terminus and M1 and A1 segments, while sagittal images are best to depict M2/M3 and A2/A3 occlusion/stenosis.

In addition to the vascular evaluation, CTA source images can be used to detect brain parenchymal ischemic changes, which correlate with low cerebral blood volume (CBV). It is more sensitive than NCCT for this purpose but can potentially overestimate core infarct volume in regions of poor but not critical hypoperfusion [20, 21].

1.4.3 Collateral Assessment

The quality of collateral flow is an important determinant of infarct progression in cases of LVO. Infarct core progresses more slowly for patients with good collaterals (slow progressors), who are more likely to tolerate the ischemic insults and benefit from thrombectomy. For patients with poor collaterals, infarct core grows more rapidly (fast progressors), and there is a relatively lower probability of penumbral salvage unless thrombectomy can be performed very rapidly [22].

CTA can provide valuable information regarding the status of collateral circulation that can be used to select candidates for thrombectomy. It can be performed as a single phase or a multiphasic study. The multiphasic study consists of arterial, peak venous, and late venous phases.

Several systems have been developed to define collateral flow based on CTA findings. For example, a commonly used system compares the collateral vessels in the region of the Sylvian fissure and cerebral convexity of the symptomatic hemisphere to the contralateral normal hemisphere with the following grading: 1, absent; 2, less than normal side; 3, equal to normal side; 4, greater than normal side; and 5, exuberant [23]. In a different system, the collaterals are graded by the degree of filling of the occluded vascular territory: 0, absent collaterals; 1, collaterals filling 50% of the territory; 2, collaterals filling > 50% but < 100% territory; and 3, collaterals filling 100% of the occluded territory [24]. A good collateral pattern can be defined as a symmetric or nearly symmetric leptomeningeal flow when comparing to the contralateral hemisphere, which can be used to select thrombectomy candidates [22].

1.4.4 CT Perfusion

CTP has become the primary modality to assess the size of core infarction and penumbra and select patients for mechanical thrombectomy in many stroke centers.

CTP is a functional technique that allows quantitative assessment of brain perfusion by acquiring serial images during the passage of a small volume of contrast (typically 30–40 ml with an injection rate of at least 4 mL/min) through the region of interest. A scan duration of 60–70 seconds is usually adequate to cover both wash-in and wash-out phases. Low peak tube potential of 80 kVp and tube current of 100–200 mAs are typically used to minimize the radiation dose.

Multiple perfusion parameters can be derived for each voxel by using various software packages, for example:

- T_{max} (time to maximum) measures the time from the start of bolus to the maximum contrast density.
- MTT (mean transit time) measures the average time for contrast bolus to pass through the voxel.
- CBF (cerebral blood flow) represents the volume of blood traversing a given amount of brain tissue per unit of time, measured in mL/100 g/min.
- CBV (cerebral blood volume) represents the volume of blood in a given amount of brain tissue measured in mL/100 g.
- CBF, MTT, and CBV are mathematically related by the central volume principle: CBF = CBV/MTT.

Analysis of CT perfusion can be made by qualitative visual assessment of parametric color maps (Figs. 1.3, 1.4, and 1.5). In cases of LVO, MTT and T_{max} are prolonged in the corresponding vascular territory, but the extent of prolongation is different for oligemia, penumbra, and core infarction. Area with severe CBV reduction usually corresponds to core infarction. Area with prolonged MTT/T_{max}, reduced CBF, but normal CBV is considered tissue at ischemic risk or penumbra (Table 1.1).

The manual post-processing and visual color map assessment require active user involvement and are subjected to great interobserver and inter-platform variability. Automated quantitative CTP analysis has been developed to address this issue and utilized in large clinical trials [8, 9]. The RAPID software uses a predefined relative CBF < 30% of normal as threshold for core infarction and T_{max} > 6 seconds for penumbra. In DEFUSE 3 trial, inclusion criteria for EVT include ischemic core infarction < 70 mL, penumbra–core mismatch volume > 15 mL, and mismatch ratio ≥ 1.8 [9].

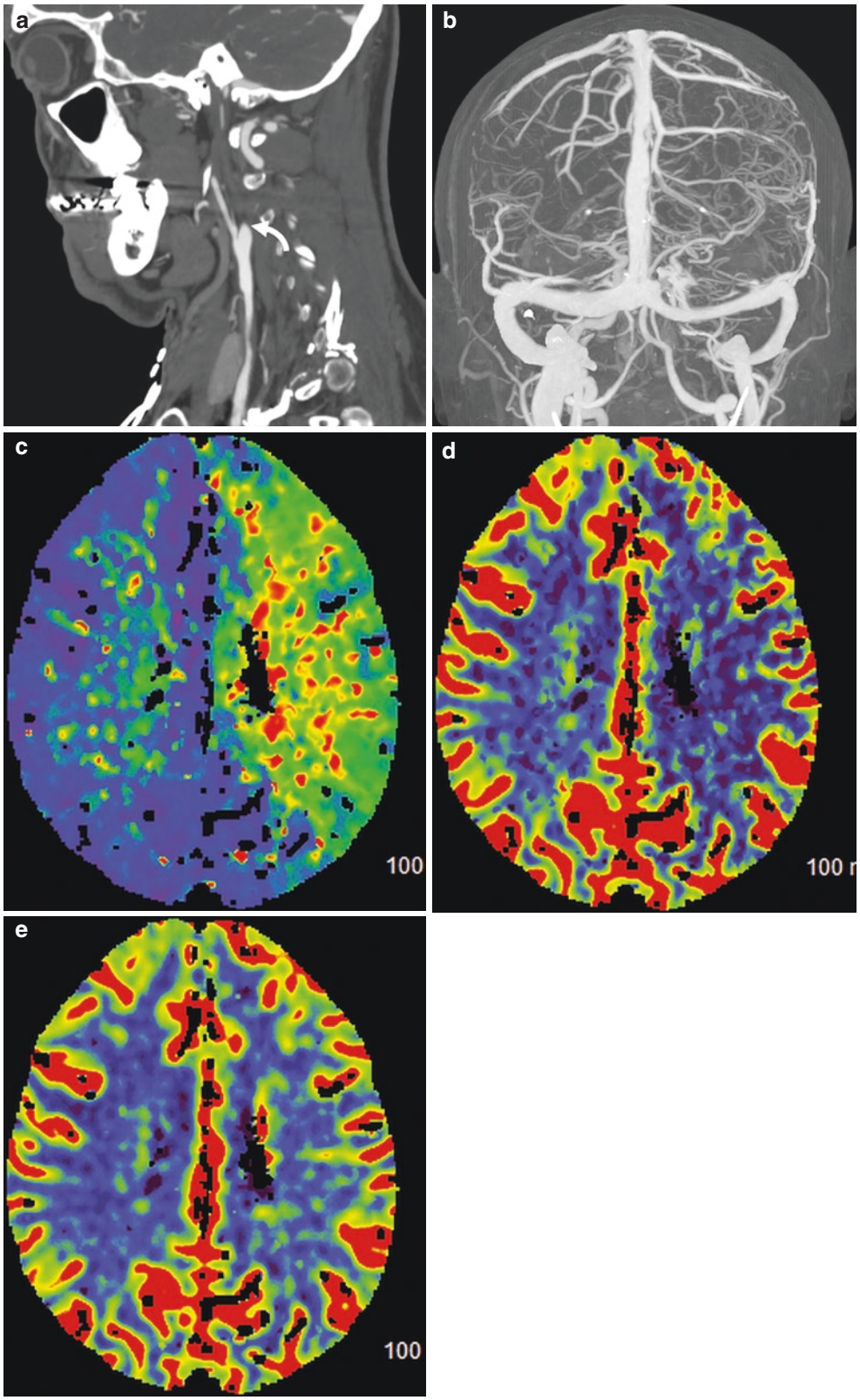

Fig. 1.3 Pattern of compensated oligemia. Young patient with recent minor injury to the neck presents with transient right-sided weakness. (**a**), CTA neck demonstrates tapered occlusion of left cervical ICA consistent with a dissection (*curved arrow*). (**b**), 3D reconstructed image of head CTA shows reconstitution of left MCA with increased vascularity compared to the right due to pial collaterals. CT perfusion demonstrates prolongation of TTD (**c**) in the left MCA and ACA territory and normal CBF (**d**) and CBV (**e**), compatible with compensated oligemia. The patient is treated with anticoagulation with no further intervention