CHAPTER 2
Use of imaging in cerebrovascular disease


1 University of Navarra, Pamplona, Spain; 2 Medical University of Vienna, Austria; 3 Donauklinikum and Donau-Universität, Maria Gugging, Austria; 4 Lariboisière Hospital, University of Paris, France; 5 Karl Franzens University, Graz, Austria; 6 University Clinic at Erlangen, Germany; 7 University Hospital Düsseldorf, Germany

Objectives

The objective of the task force is to actualize the EFNS Guideline on the use of neuroimaging for the management of acute stroke published in 2006. The Guideline is based on published scientific evidence as well as the consensus of experts. The resulting report is intended to provide updated and evidence-based recommendations regarding the use of diagnostic neuroimaging techniques, including cerebrovascular ultrasonography (US), in patients with stroke and thus guide neurologists, other healthcare professionals, and healthcare providers in clinical decision making and in the elaboration of clinical protocols. It is not intended to have legally binding implications in individual situations.

Background

Stroke is the second most common cause of death worldwide, and one of the major determining factors of hospital admission and permanent disability in the developed countries [1]. The proportion of the population over the age of 65 years is growing and this trend is likely to increase stroke incidence in the next decades [2]. Major advances in the understanding of the mechanisms of stroke and its management have been made thanks to the substantial progress in neuroimaging techniques. However, the multiplicity and continuous advances of neuroimaging techniques available for the evaluation of stroke patients has increased the complexity of decision making for physicians. Neurologists, who have been educated to manage acute stroke patients, should be trained in the use of neuroimaging, which allows for the development of a pathophysiologically oriented treatment.

Successful care of acute stroke patients requires a rapid and accurate diagnosis because the time window for treatment is narrow. In the case of intravenous thrombolysis for ischaemic stroke, the treatment is safer and more effective the earlier it is given [3]. Current recommendations call for a 4.5-h time limit for intravenous thrombolysis [4] that can be extended to 6 h for intraarterial thrombolysis [5]. Thus, the neuroimaging protocol designed to determine the cause of stroke should delay treatment as little as possible. Neuroimaging can provide information about the presence of ischaemic but still viable and thus salvageable tissue (penumbra tissue) and vessel occlusion in the hyperacute phase of ischemic stroke. This information is critical for an improved selection of patients who could be treated with intravenous thrombolysis up to the 4.5-h limit and beyond [5]. Thus, neuroimaging criteria have been used for patient selection and outcome in different trials, using thrombolysis beyond 3 h after stroke onset [6, 7]. Determining stroke type using neuroimaging goes well beyond separating ischaemic from haemorrhagic stroke. For instance, the depiction of multiple cortical infarcts may lead to a fuller work-up for cardiogenic emboli [8, 9]. In arterial dissection, the characteristic semilunar high-intensity signal in the vessel wall on high-resolution T1-weighted magnetic resonance imaging (MRI) alerts to the presence of this cause of stroke [10].
Search strategy

The Cochrane Library was consulted and no studies were found regarding the use of neuroimaging techniques in stroke. A comprehensive literature review using the MEDLINE database has been conducted by searching for the period 1965–2009. Relevant literature in English, including existing guidelines, meta-analyses, systematic reviews, randomized controlled trials, and observational studies have been critically assessed. Selected articles have been rated based on the quality of study design, and clinical practice recommendations have been developed and stratified to reflect the quality and the content of the evidence according to EFNS criteria [11].

Method for reaching consensus

The author panel critically assessed the topic through analysis of the medical literature. A draft guideline with specific recommendations was circulated to all panel members. Each panellist studied and commented in writing on this draft, which was revised to progressively accommodate the panel consensus. After the approval of the panelists, two independent experts gave their opinion on the final version.

Results

Imaging of the brain

The primary objectives of brain imaging in acute stroke are to exclude a non-vascular lesion as the cause of the symptoms and to determine whether the stroke is caused by an ischaemic infarction or a haemorrhage. It is not possible to exclude stroke mimics, such as a neoplasm, and distinguish between ischaemic and haemorrhagic stroke based exclusively on the history and physical examination [12]. Determining the nature of the lesion by brain imaging is necessary before starting any treatment, particularly thrombolysis and antithrombotic drugs (Class I, Level A).

Secondary objectives of brain imaging are to facilitate the identification of stroke mechanisms, to detect salvageable tissue, and to improve the selection of patients who could be candidates for reperfusion therapies.

Computed tomography (CT)

Conventional CT of the head is the examination most frequently used for the emergent evaluation of patients with acute stroke because of its wide availability and usefulness (Class II, Level B). It has been utilized as a screening tool in most of the major therapeutic trials conducted to date [3]. It is useful to distinguish between ischaemic stroke and intracerebral or subarachnoid haemorrhage (SAH), and can also rule out other conditions that could mimic stroke, such as brain tumours. Signs of early ischemia may be identified as early as 2 hrs from stroke onset, although they may appear much later [13]. Early infarct signs include the hyperdense middle cerebral artery (MCA) sign [14, 15] (indicative of a thrombus or embolus in the M1 segment of the vessel), the MCA dot sign [16, 17] (indicating thrombosis of M2 or M3 MCA branches), the loss of grey-white differentiation in the cortical ribbon [18] or the lentiform nucleus [19], and sulcal effacement [20]. The presence of some of these signs has been associated with poor outcome [20–22]. In the European Cooperative Acute Stroke Study (ECASS) I trial those patients with signs of early infarction involving more than one-third of the territory of the MCA had an increased risk of haemorrhagic transformation following treatment with thrombolysis [23]. A secondary analysis of other thrombolytic trials with a 6-h time window (ECASS II and Multicentre Acute Stroke Trial – Europe (MAST-E)) demonstrated that the presence of early CT changes was a risk factor for intracerebral haemorrhage (ICH) [24, 25], and similar results have been observed in larger series of patients [26]. However, in the National Institute of Neurological Disease and Stroke (NINDS) trial and the Australian Streptokinase Trial there was no relation between intracranial haemorrhage and early CT changes [27, 28], and it has been argued that the poorer outcome in patients with CT changes may have more to do with delayed treatment than with the changes themselves, with additional damage of the potentially salvageable tissue in the larger, CT-visible infarcts [29]. Because ischaemic changes are difficult to detect for clinicians without an adequate training in reading CT [30, 31], scoring systems have been developed to quantify early CT changes, such as the Alberta Stroke Programme Early CT Score (ASPECTS). More extensive early changes using ASPECTS correlate with high rates of intracranial haemorrhage and poor outcome at long term. Therefore, its use could improve the identification of ischaemic stroke
patients who would particularly benefit from thrombolysis and those at risk of symptomatic haemorrhage [32, 33]. However, given the conflicting evidence, the presence of decreased attenuation on early CT, even affecting more than one-third of the MCA territory, cannot be construed as an absolute contraindication for the use of thrombolytic therapy in the first 3 h after stroke (Class IV, Good Clinical Practice Point (GCPP)).

Conventional CT contrast enhancement is not indicated for the acute diagnosis of stroke, and seldom may be helpful to show the infarcted area in the subacute stage (2–3 weeks after stroke onset) when there may be obscuration of the infarction by the ‘fogging effect’ [34, 35] (Class IV, Level C).

Computed tomography shows acute ICHs larger than 5 mm in diameter as areas of increased attenuation. Not depicted by CT are petechial haemorrhages and bleedings in patients with very low haemoglobin levels [36], because the high density of blood on CT is a function of haemoglobin concentration. CT demonstrates the size and topography of the haemorrhage and gives information about the presence of mass effect, hydrocephalus, and intraventricular extension of the bleeding. In addition, it may identify (although not as well as MRI) possible structural abnormalities (aneurysms, arteriovenous malformations, or tumours) that caused the haemorrhage. The characteristic hyperdensity of ICH on CT disappears with time, becoming hypodense after approximately 8–10 days [37, 38]. For this reason, CT is not a useful technique to distinguish between old haemorrhage and infarction. With newer CT helical units, SAH can be detected in 98–100% of patients in the first 12 h from the onset of symptoms [39, 40] and in 93% of patients studied within the first 24 h [41, 42].

CT is the imaging procedure of choice to diagnose SAH (Class I, Level A). Some experts recommend performing the study with thin cuts (3 mm in thickness) through the base of the brain, because small collections of blood may be missed with thicker cuts [39, 43] (Class IV, GCPP). CT cannot identify SAH in patients with low haemoglobin levels, because blood may appear isodense, and in those scanned after 3 weeks of the bleeding, when blood has usually been metabolized [44]. Lumbar puncture with CSF analysis should be performed when CT scan is negative or doubtful [45].

Cerebral venous thrombosis (CVT) is an uncommon cause of stroke [46, 47]. CT can show direct signs of venous thrombosis and other indirect non-specific signs, but in about one-third of cases CT is normal [48, 49]. Direct signs on unenhanced CT are the cord sign, corresponding to thrombosed cortical veins, and the dense triangle sign, corresponding to a thrombus in the superior sagittal sinus, and, on enhanced CT of the sagittal sinus, the delta sign [50]. Indirect signs such as local hypodensities caused by oedema or infarction, hyperdensities secondary to haemorrhagic infarction, or brain swelling and small ventricles suggest the diagnosis of CVT. CT venography has emerged as a good procedure to detect CVT [51–53] (Class III, Level C).

Perfusion-CT (PCT) techniques, despite being less sensitive than diffusion-weighted (DWI) MRI can show the area of ischaemia [54, 55]. Also, may it help distinguish between reversible (ischaemic penumbra) and irreversible (infarction) areas of ischaemia with standardized methodology [56–58]. Different preliminary studies comparing PCT with MRI have shown comparable results to depict penumbral tissue [59–62]. There is only one study to date (in which the primary end point was negative) demonstrating that perfusion CT may be used for the selection of candidates to thrombolytic therapy beyond the 3-h window [63]. Pregnancy, diabetes, renal failure, and allergy to contrast material are relative contraindications to performing a perfusion brain CT. Perfusion CT may be useful to characterize the presence of marginally perfused tissue (Class II, Level B).

Magnetic resonance imaging (MRI)

Magnetic resonance imaging has a higher sensitivity than conventional CT and results in lower inter-rater variability in the diagnosis of ischaemic stroke within the first hours of stroke onset [64–69] (Class I, Level A). MRI is particularly useful to show lesions in the brain stem or cerebellum, identify lacunar infarcts, and document vessel occlusion and brain oedema [65, 66, 68] (Class I, Level A).

In addition, MRI techniques can provide information about tissue viability. DWI and perfusion (PI) MRI studies may inform about the presence of reversibly and irreversibly damaged ischaemic tissues in the hyperacute phase of stroke [70–78] (Class II, Level B). DWI may demonstrate deeply ischaemic or infarcted brain tissue within minutes of symptom onset [77]. However, areas of abnormal DWI signal are not always infarcted and the finding may disappear spontaneously or after
thrombolysis [79–81]. PI requires the intravenous administration of gadolinium and provides information about brain tissue perfusion at a given time. Different perfusion parameters give different perfusion lesion volumes in the same patient [82, 83]. The absolute volume difference or ratio of the PI area and the DWI area (diffusion–perfusion mismatch) is a useful method to estimate the presence of ischaemic penumbra tissue [84]. Not only the volume of abnormally perfused tissue but also the degree of perfusion drop predict the extent of ischaemic brain damage [85]. PI/DWI mismatch has been evaluated in several studies as a selection tool for thrombolytic therapy beyond 3 h [86–89] and in a phase II trial it was used as a selection tool and surrogate parameter for thrombolysis within 3–9 h [63]. A proposal for the standardization of perfusion and penumbral imaging techniques has been published [56].

Some neuroimaging findings on MRI, such as the presence of leukoaraiosis [90] and large DWI lesions [91], are associated with an increased risk for symptomatic intracerebral haemorrhage associated with thrombotic treatment.

MRI may be useful to predict which patients will develop massive swelling with an MCA infarct. The measurement of infarct volume on DWI allows the prediction of malignant infarction [92, 93], and may be helpful for early management of these patients [94, 95].

MRI can help identify occluded intracranial arteries by the loss of the normal intravascular flow voids [65]. Some sequences, such as T2*-weighted MRI or fluid-attenuated inversion recovery (FLAIR; hyperintense artery sign), may demonstrate acute MCA thromboembolism with a higher sensitivity than CT, but the type of arterial change on MRI does not predict recanalization, clinical outcome, or ICH after intravenous thrombolysis [96, 97].

Intracranial haemorrhage is easily detectable on MRI using T2*-weighted images [98–100]. MRI can identify intraparenchymal haemorrhage within the first 6 h after symptom onset as accurately as CT [100, 101] (Class I, Level A). Susceptibility-weighted T2* sequences (gradient echo) can also detect clinically silent parenchymal microbleeds, not visible on CT, which may leave enough local haemosiderin to remain detectable for months or years after the bleeding. Microbleeds are associated with a history of ICH and prospectively have been shown to pose a 3% risk of ICH [102]. Although some retrospective studies reported an increased risk of symptomatic haemorrhage after thrombolysis [103, 104], this risk was not found in more recent studies [82, 105, 106]. The risk of bleeding after thrombolysis in patients with microbleeds is small [106] and their presence is not a contraindication to the use of thrombolytic therapy in the first 3 h after stroke (Class III, Level C).

MRI is also useful to date the haemorrhagic event accurately and to detect lesions (as tumours, vascular malformations, or aneurysms) that may underlie the ICH [107]. To detect these lesions, repeated studies may be needed after some of the swelling and vasospasm have subsided.

Subarachnoid haemorrhage (SAH) can be detected using T2* [108] and FLAIR [109, 110] MR sequences, but at present CT remains the imaging method of choice for this diagnosis (Class I, Level A).

Arterial dissection is a leading cause of stroke in young persons [47]. MRI is the initial procedure of choice [66, 68, 111, 112], replacing conventional angiography as the gold standard (Class II, Level B), because MRI can show the mural haematoma of the dissected vessel on the axial images [112] (high signal in the wall). Visualization of these changes in the vertebral artery is more difficult than for the larger carotid artery, making diagnosis of vertebral dissection less reliable. The study can be completed with magnetic resonance angiography (MRA) to visualize occlusion of the artery, pseudoaneurysms, or a long stenotic segment with tapered ends [113, 114]. Other techniques, including US [115–117] or CT angiography [113, 114, 118, 119], may be useful for the non-invasive diagnosis of arterial dissection.

MRI combined with MRA is the method of choice for the diagnosis and follow-up of CVT [49, 120–123]. MRI is more sensitive than CT to show parenchymal abnormalities and the presence of thrombosed veins.

In summary, MRI is very helpful in the clinical setting for the management of acute stroke and to guide decisions regarding thrombolysis (Class I, Level A). It is particularly helpful for the study of stroke patients for whom perfusion CT may be dangerous, such as those with renal failure or diabetes. However, MRI in the acute phase of stroke is not widely available at European hospitals [124]. Other limitations and contraindications for the use of MRI are: claustrophobia, agitation, morbid obesity, the presence of intracranial ferromagnetic elements, an aneurysm recently clipped or coiled, otic or cochlear
implants, some old prosthetic heart valves, pacemakers, and some, not all, neurostimulators.

**SPECT and PET**

Single photon emission computed tomography (SPECT) and positron emission tomography (PET) are functional neuroimaging techniques based on the principles of tracer technology using radiolabelled substances as systemically administered tracers. In the setting of stroke, SPECT has been used for the evaluation of cerebral perfusion. Earlier perfusion SPECT studies failed to show any advantage of SPECT over the structured clinical evaluation (NIH, Canadian, Scandinavian stroke scales) in the prediction of the evolution of acute stroke [125]. However, using ethyl cystein dimer (ECD) SPECT in the first 6h after stroke, Barthel et al. [126] were able to determine which patients would develop massive MCA-territory necrosis, with hemispheric herniation. These patients have a high risk of haemorrhage following thrombolysis and could potentially be helped by early decompressive hemicraniectomy [127]. Complete MCA infarctions were predicted with significantly higher accuracy with early SPECT compared with early CT and clinical parameters. The predictive value increased when the findings on CT, clinical examination, and SPECT were considered [126]. Other studies have found SPECT to add predictive value to the clinical score on admission [128–130]. Those studies suggest that a patient with a normal SPECT study performed within 3h of stroke onset will most likely recover spontaneously and therefore may not benefit from thrombolysis. A patient with a dense deficit in the entire MCA distribution has a high risk of haemorrhage with thrombolysis, and, depending on age and other factors, should be considered for decompressive hemicraniectomy. The patients most likely to benefit from thrombolysis are the ones with less massive lesions [126, 128]. Thus, SPECT is helpful in the evaluation of acute stroke (Class III, Level C). Unfortunately, the need to perform either CT or MRI in acute stroke renders the performance of SPECT difficult within the time frame allotted for the evaluation of these patients. SPECT is also helpful in the evaluation of cerebral perfusion in non-acute cerebrovascular disease, for instance in the days after a SAH [131] (Class III, Level C).

PET can be used to evaluate a large variety of physiological variables including cerebral blood flow, cerebral blood volume, and cerebral glucose metabolism, as well as the density of neurotransmitters and neuroreceptors, such as benzodiazepine receptors with flumazenil, an accurate marker of neuronal loss [132]. As PET has been considered the gold standard for these kinds of measurements in humans, it is also extremely well suited to help identify the degree of ischaemic damage in the brain. Heiss et al. compared $^{15}$O-water PET and MRI in patients with acute ischaemic stroke. They observed that DW/PW–MRI mismatch overestimates the penumbral defined by PET [133]. Although PET is the reference method for quantitative perfusion imaging, it does not allow for the reliable identification of lesions in the vessels or non-vascular lesions giving rise to the stroke syndrome. This, coupled with the cost and current lack of availability of this technique, renders it less useful than MRI and CT for most practising neurologists.

**Imaging of the extracranial vessels**

Imaging of the extracranial and intracranial vessels will help identify the underlying mechanism of the stroke (atherothrombotic, embolic, dissection, or other). Non-invasive imaging methods are increasingly accepted as replacements of digital subtraction angiography (DSA) in the evaluation of carotid stenosis prior to endarterectomy [134] (Class IV, GCPP). US, comprising Doppler sonography and colour-coded duplex sonography, is probably the most common non-invasive imaging examination performed to aid in the diagnosis of carotid disease. The peak systolic velocity and the presence of plaque on greyscale and/or colour Doppler/Duplex US images are the main parameters that should be used when diagnosing and grading internal carotid artery (ICA) stenosis [135]. The examination may be limited by the presence of extensive plaque calcifications, vessel tortuosity and in patients with tandem lesions. In addition, Doppler US is both technician- and equipment-dependent and all sonographers should be able to demonstrate that they have validated their testing procedures. Meta-analyses of published criteria for US have demonstrated sensitivities of 98% and specificities of 88% for detecting > 50% ICA stenosis; and 94% and 90% respectively for detecting > 70% ICA stenosis [136].

Magnetic resonance angiography using time-of-flight angiography (TOF) and contrast-enhanced MRA (CEMRA) are powerful means to assess vascular pathology. Either technique provides specific information:
while TOF visualizes changes of flow in the arteries or veins depending on imaging parameters, CEMRA visualizes the vascular lumen. MRA and US have yielded comparable findings. Two meta-analyses [137, 138] and several reviews [139, 140] have compared the diagnostic value of Doppler US, MRA, and conventional DSA for the diagnosis of carotid artery stenosis. The meta-analysis published by Blakeley et al. [137] in 1995 concluded that Doppler US and MRA had similar diagnostic performance in predicting carotid artery occlusion and >70% stenosis. In the systematic review performed by Nederkoorn et al. [139] for the diagnosis of 70–99% stenosis, MRA had a pooled sensitivity of 95% and a pooled specificity of 90%, and US 86% and 87% respectively. For recognising occlusion, MRA had a sensitivity of 98% and a specificity of 100%, and DUS had a sensitivity of 96% and a specificity of 100%. A meta-analysis comparing the accuracy of TOF or CEMRA for the detection of ICA disease against intra-arterial angiography showed that CEMRA is slightly more precise than TOF for the detection of ICA high-grade (≥70 to 99%) stenosis and occlusion, and appears to achieve a higher sensitivity for the detection of moderate (50–69%) stenosis [141]. Computed tomography angiography, a contrast-dependent technique, has been compared with DSA for the detection and quantification of carotid stenosis and occlusions [142–147]. A systematic review concludes that this technique has demonstrated a good sensitivity and specificity for occlusion (97%), but the pooled sensitivity and specificity for detection of a 70–99% stenosis by CTA were 85% and 93% respectively [146] (Class II, Level B). In a systematic review, CEMRA is more accurate than CTA to adequately evaluate 70–99% carotid stenosis [148], especially when there is an excess of calcium in the plaque [149]. The difference among these modalities is small, and other factors, such as availability and quality of US performance, may render one procedure more useful than the other (Class II, Level B).

Similarly to carotid stenosis, CEMRA and CTA may be more sensitive in diagnosing vertebral artery stenosis than DUS [150].

Digital substraction angiography is the reference method to determine the degree of carotid and vertebral artery stenosis. Endarterectomy trials for symptomatic [151–153] and asymptomatic [154] patients were performed using this method. However, angiography carries the risk of stroke and death [134, 155], and many centres are not using DSA prior to carotid endarterectomy [135, 156–159], particularly when non-invasive methods are concordant (Class IV, GCPP). When non-invasive methods are inconclusive or there is a discrepancy between them, DSA is necessary.

**Imaging of the intracranial vessels**

Transcranial Doppler (TCD) and transcranial colour-coded duplex (TCCD) are non-invasive ultrasonographic procedures that measure local blood flow velocity and direction but also permit visualization of blood vessels (TCCD) in the proximal portions of large intracranial arteries [160, 161]. These methods are useful for the screening of intracranial stenosis [162–164] and occlusion [165, 166] in patients with cerebrovascular disease (Class II, Level B). In children with sickle cell disease, detection of asymptomatic intracerebral stenoses using TCD allows selection of a group at high risk of future stroke, who benefit from exchange transfusion [167] (Class II, Level B). It is also useful for the detection and monitoring of intracranial artery vasospasm after SAH, particularly in the MCA [168] (Class I, Level A). TCD can be used to monitor recanalization during thrombolysis in acute MCA occlusions [169] (Class II, Level B). There is increasing interest in its therapeutic use. In vitro studies demonstrate it has an additive effect on clot lysis when used with recombinant tissue plasminogen activator (rtPA), and clinical studies have suggested that continuous TCD monitoring in patients with acute MCA occlusion treated with intravenous thrombolysis may improve both early recanalization and clinical outcome [170]. TCD allows for the documentation of a right-to-left shunt in patients with ischaemic stroke (Class II, Level A). TCD discloses a shower of air bubbles in the MCA after the intravenous injection of saline mixed with air bubbles [171–173].

TCD is the only imaging technique that allows detection of circulating emboli, even in asymptomatic patients (Class II, Level A). Emboli cause short-duration, high-intensity signals, because they reflect and backscatter more ultrasound than the surrounding red blood cells. Studies have shown that asymptomatic embolization is common in acute stroke, particularly in patients with carotid artery disease [174, 175]. In this group the presence of embolic signals has been shown to predict the risk of stroke and transient ischaemic attack (TIA) [176–178] (Class II, Level A). Embolic signals have also been used...
as surrogate markers to evaluate antiplatelet agents in both single-centre studies [179] and in the multicentre international Clopidogrel and Aspirin for Reduction of Emboli in Symptomatic Carotid Stenosis trial [180]. Embolic signal monitoring is used to monitor embolization following carotid endarterectomy; the presence of frequent embolic signals in this setting predicts early postoperative stroke [181] and can be reduced by more aggressive antiplatelet treatment, including dextran [182] and clopidogrel [183]. TCD can also be used to evaluate cerebrovascular reserve by determining the extent to which MCA flow velocity can increase in response to the vasodilator carbon dioxide or acetazolamide. Reserve is reduced in a proportion of patients with carotid occlusion and tight stenosis, and impaired reserve predicts recurrent TIA and stroke risk, particularly in the group with carotid occlusion [184, 185] (Class III, Level B).

Transcranial Doppler examination cannot be performed in about 10–15% of patients, particularly older women, because they lack a transtemporal window due to the thickness of the skull [186]. The use of intravenous echo contrast agents may improve detection of flow velocities in patients with limited transtemporal window [187]. TCD velocities may be altered in patients with cardiac pump failure (low velocities) or anaemia (increased velocities).

Magnetic resonance angiography (MRA) can identify intracranial steno-occlusive lesions mainly in the proximal segments. Both TCD ultrasound and MRA non-invasively identify 50–99% of intracranial large vessel stenoses with substantial negative predictive value (86% and 91% respectively) [188]. Compared with DSA, MRA has a higher sensitivity and specificity (superior to 80%) for the identification of proximal intracranial arterial stenosis [189, 190] (Class II, Level B).

CT angiography is another useful technique with high sensitivity and specificity (superior to 90%) for the diagnosis of occlusion and intracranial stenosis [191, 192], with the exception of stenosis in the cavernous portion of the internal carotid or in arteries with circumferential wall calcification [189, 193] (Class II, Level B).

Magnetic resonance and CT angiography can be used to show large aneurysms (Class II, Level B), but these techniques fail to identify aneurysm of less than 5 mm in diameter, those located in the intracranial carotid artery, and cannot clearly establish the critical relationship of the neck of the aneurysm(s) with arterial branches [194–197]. Therefore non-invasive techniques have not replaced DSA for aneurysm identification and localization. The sensitivity of 3-dimensional time-of-flight MRA for cerebral aneurysms ≥5 mm after SAH is between 85% and 100% [198–200], with lower percentages for aneurysms <5 mm [45, 198, 200]. CT angiography has a sensitivity for aneurysms ≥5 mm between 95% and 100% and a specificity between 79% and 100% [45, 201–203]. Some authors suggest that CT angiography can be used as a reliable alternative to DSA after SAH, particularly in cases in which the risk of delaying surgery does not justify the performance of a catheter study [45, 204] (Class II, Level B).

MR and CT angiography have been used for screening individuals with a history of intracranial aneurysm or SAH in first-degree relatives [205, 206] (Class II, Level B). Overall reported sensitivity for both techniques was 76–98% and specificity was 85–100% [207].

DSA is needed to demonstrate small aneurysms and before surgery or endovascular treatment (Class I, Level A).

### Recommendations

**Imaging of the brain**

- Either non-contrast computed tomography (CT) or magnetic resonance imaging (MRI) should be used for the definition of stroke type and treatment of stroke (Class I, Level A).
- The presence of early CT infarct signs cannot be construed as an absolute contraindication to thrombolysis in the first 3 h after stroke (Class IV, GCPP).
- MRI has a higher sensitivity than conventional CT for the documentation of infarction within the first hours of stroke onset, lesions in the posterior fossa, identification of small lesions, and documentation of vessel occlusion and brain oedema (Class I, Level A).
- In conjunction with MRI and magnetic resonance angiography (MRA), perfusion and diffusion MR are very helpful for the evaluation of patients with acute ischaemic stroke (Class I, Level A).
- Single photon emission computed tomography (SPECT) is helpful to predict the malignant course of brain swelling with large hemispheric infarctions (Class III, Level C). SPECT is also helpful in the evaluation of cerebral perfusion in
non-acute cerebrovascular disease, for instance in the days after a subarachnoid haemorrhage (SAH) (Class III, Level C).

**Detection of haemorrhagic stroke**
- MRI can detect acute and chronic intracerebral haemorrhage (Class I, Level A).
- Although the detection of SAH is possible with MRI, currently CT scan is the diagnostic procedure of choice (Class I, Level A). In case of doubt or negative CT scan, lumbar puncture and cerebrospinal fluid (CSF) analysis is recommended (Class I, Level B).

**Imaging of extracranial vessels**
- Although MRA has slightly higher sensitivity and specificity than ultrasonography (US) to determine carotid stenosis and occlusion, the usefulness of either procedure may be determined by other factors, such as availability (Class II, Level B).
- Computed tomography angiography (CTA) has a sensitivity and specificity similar to MR for carotid occlusion and similar to US for the detection of severe stenosis (Class II, Level B).
- Digital subtraction angiography (DSA) is generally recommended for grading carotid stenosis prior to endarterectomy (Class I, Level A), but when there is concordance of non-invasive methods cerebral arteriography may not be necessary (Class IV, GCPP).

**Imaging of intracranial vessels**
- Transcranial Doppler (TCD) is very useful for assessing stroke risk of children aged 2–16 years with sickle cell disease (Class II, Level B), detection and monitoring of vasospasm after SAH (Class I, Level A), diagnosis of intracranial steno-occlusive disease (Class II, Level B), diagnosis of right-to-left shunts (Class II, Level A), and for monitoring arterial recanalization after thrombolysis of acute middle cerebral artery (MCA) occlusions (Class II, Level B).
- TCD can detect cerebral emboli and impaired cerebral haemodynamics. The presence of embolic signals with carotid stenosis predicts early recurrent stroke risk (Class II, Level A). The detection of impaired cerebral haemodynamics in carotid occlusion may identify a group at high risk of recurrent stroke (Class III, Level B).
- MRA and CTA are very useful for the diagnosis of intracranial stenosis and cerebral aneurysms >5 mm (Class II, Level B). MRA and CTA are the recommended techniques for screening cerebral aneurysms in individuals with a history of aneurysms or SAH in a first-degree relative (Class II, Level B).
- DSA is the recommended technique for the diagnosis of cerebral aneurysm as the cause of SAH (Class I, Level A). CTA can be used as a reliable alternative to DSA in patients with SAH, particularly in cases in which the risk of delaying surgery for a catheter study is not justified (Class II, Level B).
- MRI with MRA is recommended for the diagnosis and follow-up of cerebral venous thrombosis (Class II, Level B). Alternatively, CT venography is accurate and can be used for the same purpose (Class III, Level C).

**Conflicts of interest**
J. Masdeu received an honorarium as Editor-in-Chief of the *Journal of Neuroimaging*. With regard to this manuscript there is no conflict of interest.

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