

Imaging of stroke and transient ischaemic attack

Non-fatal stroke has significant social and financial implications, and the use of appropriate imaging is essential for early diagnosis and treatment to prevent permanent disability. This article discusses the pivotal role radiological imaging plays in the management of stroke and transient ischaemic attack.

Stroke is the third commonest cause of death in the UK following heart disease and cancer, with an estimated 150 000 new events and 67 000 deaths directly attributable to stroke each year (Office of National Statistics, 2001). The disease burden on society is enormous, with the majority of strokes being non-fatal, leaving the individual with disability and dependence. The estimated direct cost to the NHS is £2.8 billion (National Audit Office, 2005).

National programmes to improve cardiovascular disease aim to promote stroke prevention long term, but to those individuals suffering an acute event, this is of little solace. Training clinicians in the early detection and treatment of stroke has significant implications for the potential recovery and permanent disability a patient may suffer. Radiological imaging plays a pivotal role in the management of both stroke and transient ischaemic attack with several modalities available to promote high diagnostic yield. Requesting the correct investigation at the right time can dictate treatment decisions and improve patient care in both the acute and chronic setting. This article provides an overview of imaging modalities used in patients presenting with probable stroke or transient ischaemic attack.

Definitions

A stroke is a cerebrovascular accident where brain cells are starved of oxygen because blood flow is impaired by either blockage (secondary to thrombosis or embolus) or rupture (haemorrhage) of a blood vessel.

A transient ischaemic attack is a neurological event with the signs and symptoms of a stroke, which spontaneously and completely resolves within 24 hours.

Imaging modalities

The following imaging modalities may be used in patients presenting with a suspected stroke or transient ischaemic attack:

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Ultrasound

Carotid ultrasound is a useful tool in assessing the presence and severity of cervical carotid artery disease and can help to identify patients who may have a surgically treatable carotid stenosis. Ultrasound assessment is therefore useful in patients with anterior circulation symptoms, as patients with posterior circulation symptoms or those who have a disabling stroke with no recovery are not operative candidates. The indications for ultrasound referral include:

1. Evaluation of patients with hemispheric neurological symptoms including transient ischaemic attack or amaurosis fugax
2. To further investigate non-disabling stroke – patients with anterior circulation stroke symptoms that last more than 24 hours but later resolve leaving no permanent disability
3. Evaluation of patients with a carotid bruit on examination
4. Evaluation of a pulsatile neck mass
5. Follow up of patients with proven carotid artery disease.

Ultrasound is a cheap, non-invasive and accessible modality that does not put the patient at risk of radiation exposure. It is reliable at grading carotid stenoses and its only major drawback is its dependency on operator experience (Thomas and Maldonado, 2007).

Atheromatous plaque formation within the carotids, often involving the carotid bulb or bifurcation, causes vessel narrowing and turbulence of blood flow. Ultrasound in carotid assessment works by evaluating the flow velocity and waveform of blood as it passes through the carotid arteries. A linear high frequency ultrasound (7–15 Mhz) generates a greyscale image to directly visualize plaque disease and help characterize it according to its echogenicity and the presence of calcification. Plaques that are echopoor have a high content of fat, making them softer and more susceptible to rupture and embolization causing a thromboembolic stroke. Plaques with a high degree of calcification appear echogenic and are more stable.

The atheromatous plaque also reduces the carotid artery lumen and changes to the blood velocity and turbulence can be measured with Doppler studies and graded according to the degree of stenosis (Figures 1a and b).

Doppler estimates the average flow velocity within a vessel by using the 'Doppler effect', where the frequency of a sound wave changes as it is reflected by the moving red blood cells. As stenosis of the vessel increases, the flow velocity changes and this is detected sonographically. Doppler can identify peak systolic and end diastolic velocities post-stenosis, as well as the peak systolic velocity ratio between the internal carotid and the common carotid arteries. The degree of stenosis can be estimated and correlated to the risk of stroke (Nicolaidis et al, 1996). Patients with a carotid lesion who require surgery should be referred urgently to reduce the patient's risk of further events. The North American Symptomatic Carotid Endarterectomy Trial (1991) has established guidelines for possible surgical intervention based on the ultrasound results. Stenoses are classified into:

1. Moderate (51–70%)
2. Severe (71–90%)
3. Critical (91–99%)
4. Occlusal (100%).

The trial found that the absolute risk of having an ipsilateral major or fatal stroke within 2 years, in a patient with recent symptoms and a lesion >70%, was 10.3%. These patients benefit from carotid endarterectomy.

Echocardiography is cardiac ultrasound and is used in patients with cerebrovascular accident or transient ischaemic attack where the heart is thought to be the possible source of embolism. Patients suffering from endocarditis can suffer septic embolization from heart valve vegetations. Similarly, thromboembolic strokes can occur in patients suffering from atrial myxomas (Maroon and Campbell, 1969) or left ventricular thrombus post-myocardial infarction. An echocardiogram can directly visualize the heart chambers and exclude these as possible causes of stroke.

Computed tomography

Conventional computed tomography is widely used in all aspects of brain pathology and is the 'workhorse' of stroke imaging. Being relatively cheap and usually accessible 24 hours a day, computed tomography provides enormous diagnostic capabilities through cross-sectional imaging of the brain. Performing a computed tomography scan is quick and with the advent of multislice scanning systems, the brain can be imaged in its entirety in a few seconds. This is useful in stroke patients who are often unwell, confused and agitated. Computed tomography scans have a high resolution and are excellent at resolving acute blood within the brain parenchyma and identifying stroke mimics. Most strokes are thromboembolic (90%) in aetiology, and less commonly haemorrhagic. Computed tomography scans can differentiate between the two as treatment pathways for infarction require antiplatelet or anticoagulant therapy, while haemorrhage needs to be excluded to avoid the potentially catastrophic effects of anticoagulation.

Referral for computed tomography should be by an experienced clinician, as unnecessary scans can expose the patient to needless amounts of ionizing radiation that potentially have significant long-term consequences. Always discuss complex cases with a radiologist and liaise closely with the computed tomography staff to ensure patients are cooperative and stable to facilitate safe scanning.

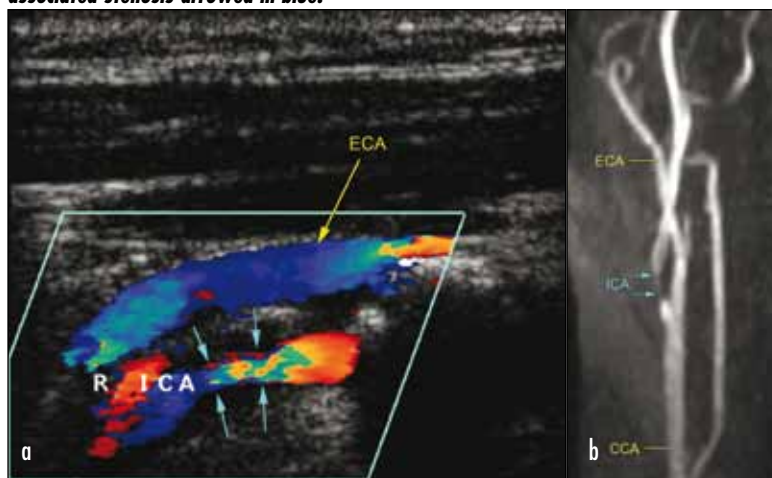
Computed tomography angiography can obtain cross-sectional images in the arterial phase of contrast enhancement, and is used to highlight aneurysms, carotid stenoses and in the acute setting to demonstrate cerebral artery occlusion (Simms et al, 2005).

Perfusion computed tomography

Perfusion computed tomography is a dynamic study that monitors brain perfusion and parenchymal function. Although currently a research tool, it is being suggested as a primary imaging modality. A small contrast load is instilled intravenously and several slices of a computed tomography scan are performed at the same level over a fixed period of time. Attenuation changes are monitored and cerebral blood flow and volume, mean transit time and time to peak enhancement can be measured. This is useful for two reasons:

1. Disruption to brain perfusion can be detected early after clinical symptoms
2. Joint assessment of perfusion computed tomography with conventional cranial computed tomography

Figure 1. a. Ultrasound demonstrating a longitudinal view of the right common carotid artery (CCA) bifurcating into the internal and external branches (yellow arrow). At the origin of the internal carotid artery (ICA) there is narrowing within the lumen from atherosclerotic plaque disease (blue arrows). The blood velocity was consistent with a severe (89%) stenosis. As the patient had recently suffered a transient ischaemic attack on this side, he was referred for surgical assessment in keeping with the North American Symptomatic Carotid Endarterectomy Trial guidelines. b. Magnetic resonance angiography of the same patient confirms irregular narrowing at the origin of the ICA with severe stenosis seen. The ICA distal to this can be identified, excluding the possibility of complete occlusion. This study would help vascular surgeons plan the endarterectomy. The CCA and external carotid (ECA) arteries are arrowed in yellow, with ICA and associated stenosis arrowed in blue.



allows clinicians to assess the degree of reversibility following a stroke (Miles and Griffiths, 2003). Treatment decisions can then be made on how aggressive the stroke rehabilitation should be to try and regain some or all of the pre-morbid function.

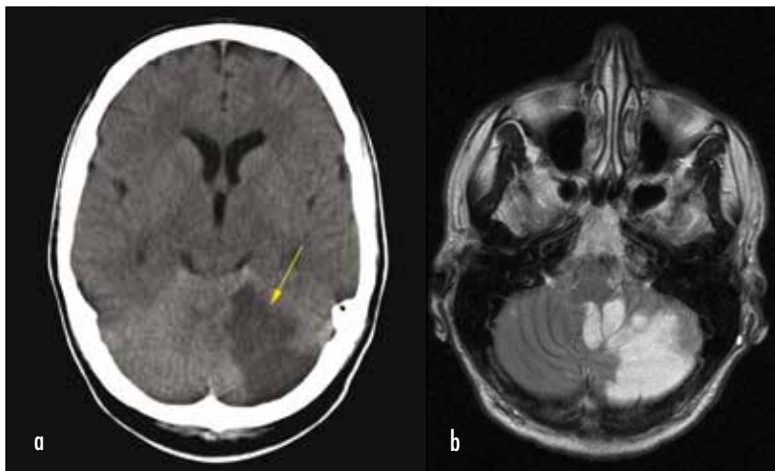
Although not established practice in most hospitals yet, perfusion computed tomography may have a significant role to play in the future management of stroke, as small or early thromboembolic strokes demonstrated by perfusion computed tomography often have normal conventional computed tomography appearances.

Magnetic resonance imaging

The physics of magnetic resonance imaging are complex and are beyond the scope of this article, but by manipulating hydrogen ions with radiofrequency pulses, powerful computers can generate cross-sectional images through the brain. Magnetic resonance imaging does not use ionizing radiation, and the multiplanar images produced have a high spatial and contrast resolution. Magnetic resonance imaging is beneficial in monitoring the parenchymal response to thromboembolic stroke (Figures 2a and b) and has a high sensitivity in diagnosing both ischaemic (83%) and haemorrhagic (81%) stroke in the emergency setting (Chaldla et al, 2007).

Although magnetic resonance imaging is an exciting modality with enormous diagnostic potential, it is limited by its expense and availability. The scan duration is also significantly increased compared to computed tomography studies, and in stroke patients who are often agitated and require constant monitoring, this can potentially compromise patient care and degrade the images produced. For these reasons, magnetic resonance imaging is not a first-line investigation at this time, but

Figure 2. a. A wedge-shaped area of low attenuation is seen in the left cerebellar hemisphere (arrowed), with slight effacement of the left quadrigeminal basal cistern. These features are consistent with an acute cerebellar infarct and associated parenchymal oedema. **b.** This T2-weighted magnetic resonance imaging sequence of the same patient as Figure 2a demonstrates an ill-defined area of high signal in the left cerebellar hemisphere emphasizing the extent of oedema seen on the computed tomography scan.



it is a useful adjunct to computed tomography as a second-line problem-solving tool. Its role is certain to increase in the future, because continuing advances in technology have improved scan sequences like diffusion weighted imaging, which can accurately follow the diffusion of water molecules and demonstrate pathological changes in parenchymal oedema during a stroke or transient ischaemic attack (Figure 3). The use of diffusion weighted imaging in transient ischaemic attack assessment is recognized by the National Institute for Health and Clinical Excellence, which now recommends this as the sequence of choice in high-risk (ABCD2 > 4) individuals (Calvet et al, 2009). Diffusion weighted imaging can potentially identify patients with ischaemia requiring treatment that have normal computed tomography and conventional magnetic resonance imaging.

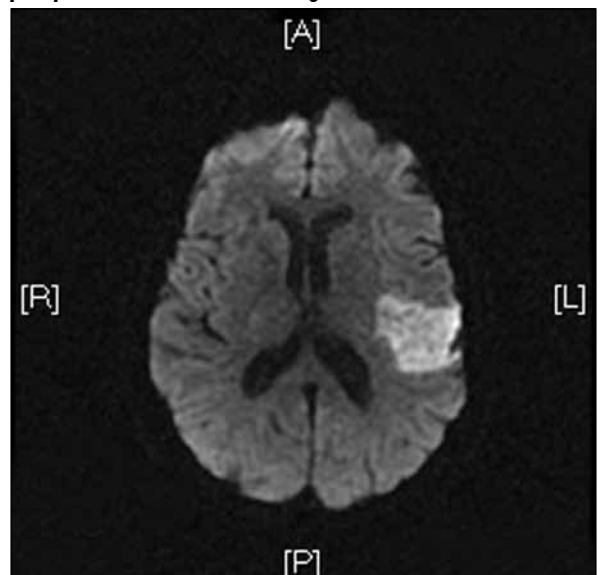
Magnetic resonance angiography uses a specific sequence to highlight the flow of blood through arteries, and is very useful in detecting and characterizing arterial aneurysms and stenoses both within the brain and in the cervical carotid arteries.

Chest radiograph

A chest X-ray should be performed in all patients presenting with possible stroke or transient ischaemic attack. Although this will not reveal the type of stroke, an admission or assessment chest X-ray is important for several reasons:

1. Loss of higher cortical function commonly impairs a patient's ability to swallow, and puts him/her at

Figure 3. This patient had a suspected transient ischaemic attack involving the right arm with a normal computed tomography scan. Magnetic resonance imaging was also normal on conventional sequences, but the diffusion weighted imaging showed increased signal in the left parietal lobe consistent with ischaemia, allowing prompt initiation of further investigation and treatment.



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- increased risk of aspiration. Chest X-ray can detect aspiration pneumonia or act as a baseline reference should there be future respiratory deterioration
2. Chest X-ray can detect any concomitant thoracic illness, for example a primary lung cancer that can increase pro-thrombotic risk, or suggest metastatic disease that can mimic stroke presentation
 3. Reversible cerebrovascular accident sequelae need to be excluded, e.g. congestive cardiac failure
 4. Vascular calcification can imply a background of cardiovascular disease, and can demonstrate cardiomegaly or sequelae of systemic hypertension
 5. Chest X-ray can exclude the possibility of thoracic aortic aneurysm in cases of possible stroke that would otherwise contraindicate thrombolysis therapy.

Computed tomography of stroke

The clinical symptoms of stroke depend on the neuronal pathways damaged by the interruption to their blood supply. A good history and examination should be able to localize the territory involved, with computed tomography required to confirm the clinical findings and differentiate infarction from haemorrhage and possible stroke mimic. It is important to remember that decussation of long tracts within the brainstem results in symptoms on the contralateral side to the hemispheric brain lesion. Common presenting symptoms are:

1. Unilateral weakness (hemiplegia) of the face, arms or legs
2. Unilateral numbness of the face, arms or legs
3. Slurred speech
4. Ataxia and clumsiness
5. Visual disturbances.

These presenting features have been classified by Bamford et al (1991), as shown in *Figure 4*.

Although neurological deficit is most commonly caused by stroke, there are non-vascular causes that can be indistinguishable in clinical presentation. Termed 'stroke mimics', they can be caused by a primary CNS problem, or sequelae of systemic disease. Computed tomography is used in the first instance to differentiate between a haemorrhagic or ischaemic event and a stroke mimic (Widjaja et al, 2005), and this is important should criteria be met to offer interventional stroke therapy. Stroke mimics include:

1. Subdural or extradural haemorrhage
2. Bleeding from vascular malformations
3. Normal pressure hydrocephalus
4. Multiple sclerosis
5. Mass lesions including tumour and abscess
6. Seizure disorder and post-ictal states
7. Metabolic derangement including hypoglycaemia and hyponatraemia
8. Migraine
9. Functional and psychological hemiparesis.

Stroke is a preventable and treatable disease, and the National Institute for Health and Clinical Excellence (2008) has issued national guidance on its management. Although several stroke scales have been suggested, the National Institute for Health and Clinical Excellence recognizes the FAST (face, arm and speech test) in the community and the recognition of stroke in ER (ROSIER) scale on admission to accident and emergency. The ROSIER scale is designed to provide physicians with a stroke recognition instrument to make effective assessment and triage. It uses rapidly available aspects of the history and physical examination, focusing on asymmetrical facial, arm or leg weakness with associated speech or visual field disturbance. Negative marks are given for evidence of seizure or episodes of syncope, and a score between -2 and +5 is generated (Nor et al, 2005). A ROSIER score >0 is consistent with an acute stroke. A patient should have an urgent computed tomography immediately and if criteria are met, the patient may be eligible for thrombolysis. A score of <0 implies a low probability of stroke.

There are strict inclusion and exclusion criteria for stroke thrombolysis, and a list of these are available in the accident and emergency department of any hospital that uses this intervention. The role of computed tomography is to exclude any of the following neuroradiological contraindications to thrombolysis:

1. Intracranial haemorrhage
2. Cerebral oedema
3. Involvement of more than one third of the middle cerebral artery territory
4. Severe deep white matter ischaemia present
5. Prior major stroke in the past 3 months
6. Large cortical infarcts with mass effect
7. Pathology other than an acute infarction that can explain the symptoms.

Recombinant tissue plasminogen activator is used for thrombolysis and administered as a bolus dose followed by a continuous infusion.

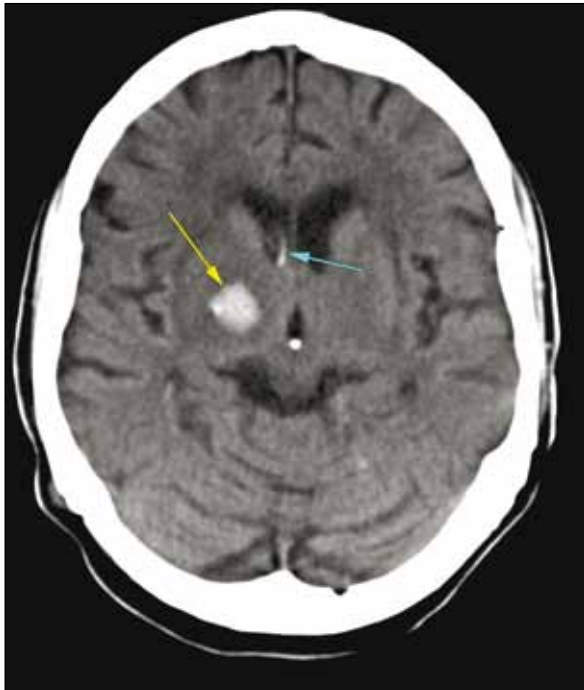
Most hospitals should now offer a 24-hour computed tomography service for the assessment and treatment of cranial pathology. Computed tomography has a high sensitivity for detecting intraparenchymal haemorrhage (89%) (Chaldia et al, 2007), and in the acute setting is significantly more sensitive than magnetic resonance imaging in diagnosing haemorrhagic stroke (Hoggard et

Figure 4. Presenting features of stroke as classified by Bamford et al (1991).

Total anterior circulation syndrome	Hemiparesis + higher cortical dysfunction + hemianopia
Partial anterior circulation syndrome	Isolated higher cortical dysfunction OR any two of hemiparesis, higher cortical dysfunction and hemianopia
Posterior circulation syndrome	Isolated hemianopia OR brainstem syndrome
Lacunar syndrome*	Pure motor stroke OR pure sensory stroke OR sensorimotor stroke OR ataxic hemiparesis OR clumsy hand-dysarthria
*Lacunar strokes are small deep infarcts measuring less than 1.5 cm in diameter. Commonly in perforator arteries of the basal ganglia, they can cause dense neurology despite their small size	

al, 2002). Acute blood within the brain parenchyma appears homogeneously white on computed tomography in contrast to adjacent darker brain tissue (*Figure 5*). Over time, the static blood breaks down, causing variable

Figure 5. A 16 mm focus of hyperintensity is seen in keeping with an acute intracerebral haemorrhage in the right thalamic region (yellow arrow). There is associated surrounding low density oedema and mass effect, and a curvilinear streak of high attenuation seen within the right lateral ventricle from intraventricular extension (blue arrow).



attenuation appearances and associated parenchymal atrophy. The computed tomography sensitivity for thromboembolic stroke is much lower (45% at ictus rising to 74% by day 11) (Dahnert, 2007) and can be classified into acute or chronic depending on the computed tomography appearances.

Acute

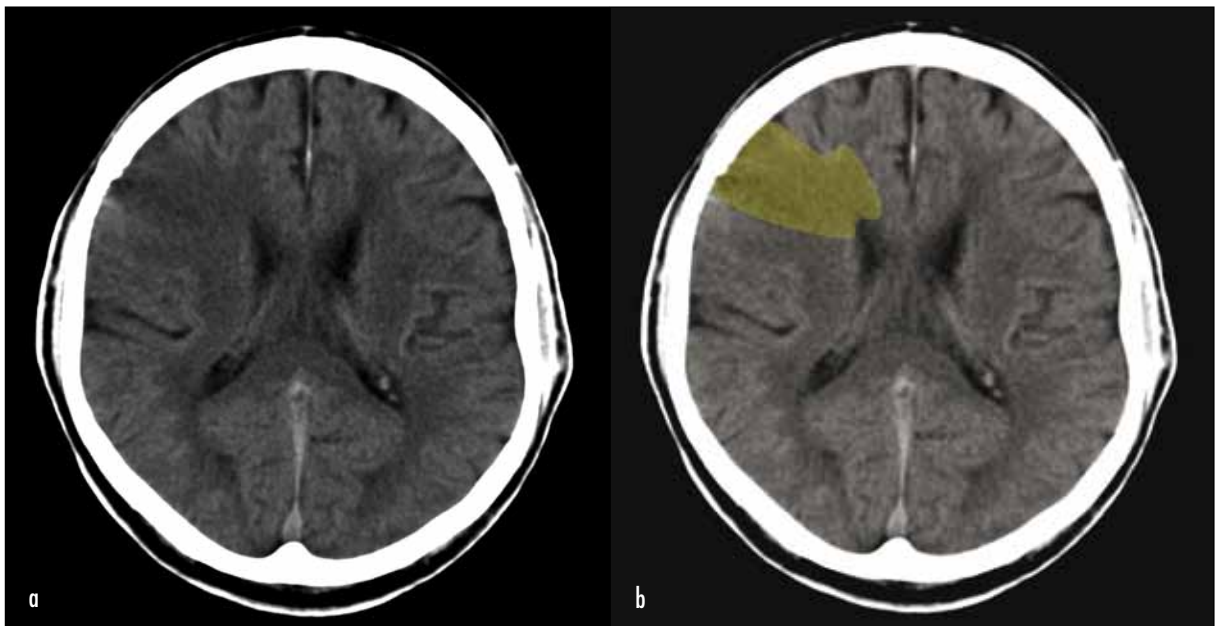
Early (<6 hours) after thromboembolic stroke, cranial computed tomography can be normal in up to 55% of cases. Depending on the size of the infarct, other appearances include:

1. Subtle decreases in brain density compared to the contralateral side, with loss of grey/white matter differentiation (*Figures 6a and b*)
2. Sulcal and ventricular effacement from mass effect as the brain swells
3. Acute intraluminal thrombus in the middle cerebral artery can cause a ‘dense artery sign’ in the Sylvian fissure (*Figure 7*)
4. A hypodense wedge-shaped lesion in the distribution of the vascular territory involved can be seen in the late acute phase.

Chronic

Failure to re-vascularize the infarcted brain parenchyma causes gliosis, demyelination and cerebral atrophy. Computed tomography demonstrates a well-demarcated wedge-shaped area of encephalomalacia with increased sulcal spaces and loss of brain volume (*Figure 8*). Occasionally, small areas of hyperdense haemorrhage can be seen within this, as acute bleeds can occur in areas of infarction.

Figure 6. a. Within the right fronto-parietal region there is loss of grey/white matter differentiation and some sulcal effacement compared to the contralateral side. **b.** This area is shaded in yellow. These are the subtle features of an acute thromboembolic stroke in the distribution of the right middle cerebral artery.



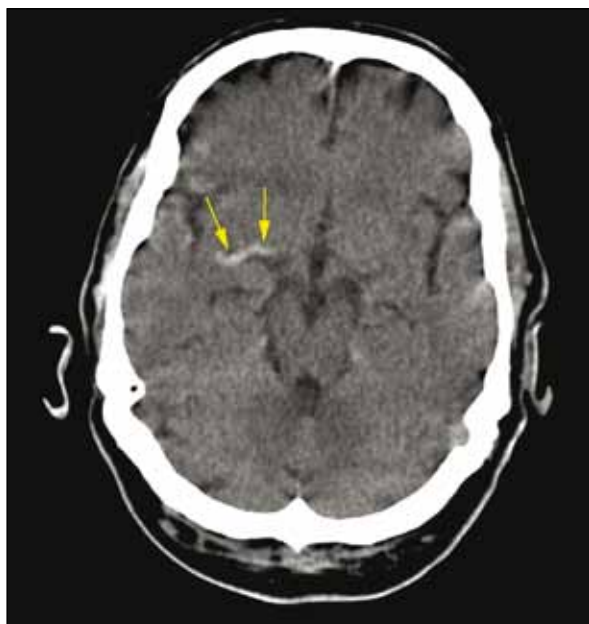
Computed tomography is also useful in those patients who have undergone stroke thrombolysis therapy but clinically deteriorate following this intervention, or in patients with a stroke demarcated on computed tomography who then deteriorate (?extension of infarct or bleed into infarct).

Imaging in transient ischaemic attack

The significance of patients presenting with a transient ischaemic attack should not be underestimated, and these patients should be considered an acute medical emergency (Johnston et al, 2000). Following a transient ischaemic attack, patients have a 17.3% chance of experiencing a debilitating or fatal stroke within the following year if untreated (North American Symptomatic Carotid Endarterectomy Trial Collaborators, 1991), and the presenting transient neurological deficit is a warning indicating the increased risk of further thromboembolic events. Urgent assessment is essential, and medical treatment must be instigated to reduce atheroma formation and promote plaque stability. Patients who have a surgically treatable lesion need identification, with urgent vascular referral and definitive surgical treatment to prevent a possible cerebral vascular accident. Timing is important, and all the above needs to happen within days, and not weeks as has often been the case.

The risk of further stroke in those patients following a suspected transient ischaemic attack can be assessed using a validated scoring system. National Institute for Health

Figure 7. A patient presenting with 6 hours onset of left-sided arm and leg weakness underwent an unenhanced head computed tomography study which was found to be normal apart from this area of linear high density within the right Sylvian fissure (yellow arrows). This finding can be seen in unenhanced computed tomography studies following an acute stroke, and is the 'dense artery sign' of acute right middle cerebral artery thrombus.



and Clinical Excellence recognize the ABCD2 system, as shown in *Figure 9*. Any patient with an ABCD2 score of >4 or a history indicative of crescendo transient ischaemic attack should be treated in an emergency capacity to prevent a subsequent disabling stroke. Urgent brain imaging should be undertaken and secondary preventative measures of good blood pressure, glycaemic and lipid control should be initiated.

Other transient ischaemic attack patients with an ABCD2 score of <4 should be referred to a stroke specialist for assessment within 1 week before decisions are made on further brain imaging, as although the ABCD2 score has a good predictive value, those patients with a score of <4 still have a risk of non-fatal stroke (Cucchiara et al, 2007).

As discussed previously, an unenhanced conventional computed tomography scan in these patients is usually normal but is still required to exclude stroke mimics. Unless contraindicated, the imaging modality of choice

Figure 8. Failure to revascularize infarcted brain parenchyma leads to gliosis. This unenhanced computed tomography study demonstrates a chronic and well-established right middle cerebral artery infarction, with associated encephalomalacia and cerebral atrophy.



Figure 9. ABCD2 algorithm for risk of stroke or transient ischaemic attack.

Age	≥60 years = 1 point
Blood pressure	A systolic >140 mmHg or diastolic >90 mmHg = 1 point
Clinical features	Unilateral weakness = 2 points Isolated speech disturbance = 1 point All others = 0 points
Duration of transient ischaemic attack symptoms	>60 minutes = 2 points 10–59 minutes = 1 point
Diabetes	If present = 1 point

in high-risk individuals is a diffusion weighted magnetic resonance imaging scan. This can demonstrate subtle parenchymal oedema changes secondary to ischaemia that would not be visible on a computed tomography scan. Computed tomography should be supplemented with a carotid artery ultrasound scan in accordance with the North American Symptomatic Carotid Endarterectomy Trial guidelines. Combining a good clinical history and examination with the imaging findings dictates whether or not the patient is suitable for an endarterectomy. Patients who do not fit the criteria or are not suitable for surgery should be given prompt medical treatment, anti-platelet agents and management of risk factors (e.g. diabetes, hypertension and obesity).

Conclusions

The management of stroke and transient ischaemic attack requires a multidisciplinary approach with radiology being pivotal in the management and treatment of both thromboembolic and haemorrhagic events. Radiology excludes neurological deficits secondary to stroke mimics, and can triage stroke or transient ischaemic attack patients with respect to medical or surgical treatment options. Computed tomography is the workhorse of stroke management and, with ease of accessibility and the advent of new techniques including perfusion computed tomography, its use will only increase. Cranial and cervical carotid magnetic resonance imaging is of diagnostic benefit, and has been recognized nationally with emphasis on diffusion weighted imaging and magnetic resonance angiography in the management of transient ischaemic attack.

The importance of early investigation and treatment of transient ischaemic attack should not be underestimated, and ultrasound is enormously beneficial in the diagnosis of surgically treatable lesions, to reduce the risk of further disabling or fatal stroke. Echocardiography can be diag-

nostic should a cardiac cause of stroke be suspected, and plain film radiology is a useful adjunct to other modalities to screen patients and treat potential stroke-related sequelae.

Disabling stroke has enormous implications for both patients and their families, with increased dependence on health-care provision. A patient-centred approach to the management of transient ischaemic attack and stroke is of paramount importance. Clinicians should use radiology resources for early intervention, and help guide treatment options to improve outcome and reduce morbidity long term. **BJHM**

Conflict of interest: none.

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KEY POINTS

- Radiological imaging plays a pivotal role in the management of both stroke and transient ischaemic attack, with several modalities available to promote high diagnostic yield.
- Early diagnosis is essential in preventing non-fatal disabling stroke which carries enormous physical, social and financial implications.
- Computed tomography is the workhorse of stroke management, with cranial and cervical carotid magnetic resonance imaging of additional diagnostic benefit.
- The importance of early intervention and treatment of transient ischaemic attack should not be underestimated. It is a warning of impending stroke and should be managed as a medical emergency.
- The management of stroke and transient ischaemic attack requires a multidisciplinary approach with radiology playing a central role.