CHAPTER 2
ACUTE AND CRITICAL STROKE CARE

Skye Coote, NP,MN, BN, RN, ANVP-BC, CCRN
Nurse Practitioner and Nursing Coordinator, Melbourne Mobile Stroke Unit, Melbourne Health, Melbourne, Victoria Australia

Anne W. Alexandrov, PhD, RN, CCRN, NVRN-BC, ANVP-BC, FAAN
Professor & Chief Nurse Practitioner, University of Tennessee Health Science Center-Memphis and Mobile Stroke Unit, Tennessee USA; Program Director, NET SMART, Health Outcomes Institute, Fountain Hills, Arizona USA

LEARNING OUTCOMES: After completing this chapter you will be able to:

1. Identify the incidence and impact of stroke in the community
2. Describe the major anatomical areas of the brain and the major arterial vessels within the brain.
3. Classify the mechanisms of stroke and the symptomatology of stroke depending on the location of the brain ischemia.
4. Describe the immediate and ongoing care requirements and options available to a patient suffering an ischemic or haemorrhagic stroke.
5. Describe the important pharmacological agents associated with stroke care including key safety precautions and considerations to avoid further harm.

DEFINITIONS:
ACA – anterior cerebral artery
AcomA – anterior communicating artery
AF – atrial fibrillation
aSAH – aneurysmal subarachnoid haemorrhage
AVM –arteriovenous malformation
BP – blood pressure
BiPAP - bi-level positive airway pressure
CO2 – carbon dioxide
CPAP – continuous positive airway pressure
CPSS - Cincinnati Pre-hospital Stroke Scale
CN – cranial nerve
CNS – central nervous system
CSF –cerebrospinal fluid
CTA - computed tomography angiogram
CTP - computed tomography perfusion

DOAC – direct oral anticoagulant
ECR – endovascular clot retrieval
ED – emergency department
EOM - extra ocular movement
EVD – external ventricular drain
GCS – Glasgow coma scale
HOB – head of bed
HT – hypertension
IV t-PA - intravenous tissue plasminogen activator (alteplase)
MRI - magnetic resonance imaging
NIBP – non invasive blood pressure
NIHSS - National Institutes of Health Stroke Scale (NIHSS)
NCCT - non contrast computed tomography scan
IPH - Intraparenchymal haemorrhage
LOC – level of consciousness
LAPSS - Los Angeles Pre-hospital Stroke Scale
MASS - Melbourne Ambulance Stroke Scale
SAH – Subarachnoid haemorrhage
sICH - symptomatic intracerebral haemorrhage
TIA – transient ischemic attack
VTE - venous thromboembolism
WHO – World Health Organisation

INTRODUCTION

Stroke is a global disease burden with more than 15 million strokes occurring worldwide each year. In the United States of America (USA), a stroke occurs every 40 seconds (1, 2). Stroke is the leading cause of major disability in the United Kingdom (1), and in Australia more than half of all stroke survivors are left with permanent disability (3). The long-term cost of caring for stroke patients is immense; in 2010 in the USA alone, stroke-related costs exceeded $70 billion (2), these costs are substantially higher in low- and middle-income areas (4). The World Health Organization (WHO) reports these extreme costs may result in increased mortality and morbidity rates in low socioeconomic countries (1).

Stroke is a clinical condition characterized by the sudden interruption of the blood supply to the brain, retina, and/or spinal cord (5). It is a vascular disease, caused by a blocked artery (ischaemic stroke) or a burst blood vessel (haemorrhagic stroke). A stroke disrupts blood flow, thereby limiting the supply of oxygen and nutrients, resulting in tissue death (1). Stroke classically produces a sudden onset of neurological symptoms, most commonly unilateral in nature, which can be ascribed to specific vascular territories. The scope and severity of stroke symptoms can range from mild to severe. Even if symptoms resolve, tissue death may still have occurred (5). Stroke symptoms which spontaneously resolve with no infarction may be diagnosed as either a transient ischemic attack, or in the case of thrombolytic treatment, an aborted stroke (5, 6). Acute stroke is a time critical medical emergency; there are a limited number of treatment options available, and most have a set time frame in which treatment must be initiated. Seeking urgent medical care at a designated Stroke Centre hospital is paramount to achieve best possible outcomes (7, 8).

ANATOMY

The cerebrum

The cerebrum makes up 80% of the brain's weight and is divided into right and left hemispheres (9, 10). It consists of an outer layer of grey matter called the cerebral cortex, and a subcortical white matter layer. Subcortical axons are responsible for conducting impulses from the grey matter to other regions of the Central Nervous System (CNS).

The cerebral cortex is divided into 4 lobes: frontal, parietal, temporal and occipital. The frontal lobes are separated from the parietal lobes by the central sulcus and from the temporal lobes by the lateral (Sylvian) fissure. The parietooccipital fissure divides the parietal lobes from the temporal and occipital lobes. (*Figure 1*)

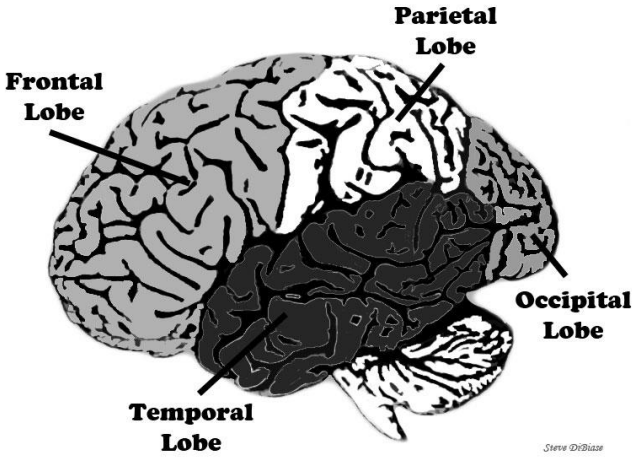

Figure 1: *The four lobes of the cerebral cortex. Reprinted with permission from NET SMART (www.learnstroke.com), Health Outcomes Institute, LLC.*

Primary functions of the cerebral cortex include language, motor control, sensation recognition and intellect – functions that are unique to Homo sapiens. In 1909, Dr Korbinian Brodmann, a German neurologist attempted to localize these cortical functions by mapping their specific regions. Brodmann's Classification of the Cerebral Cortex is incomplete, but the mapped areas allow us to gain a greater appreciation of brain function and the implications of cortical stroke damage (11) (*Figure 2*).

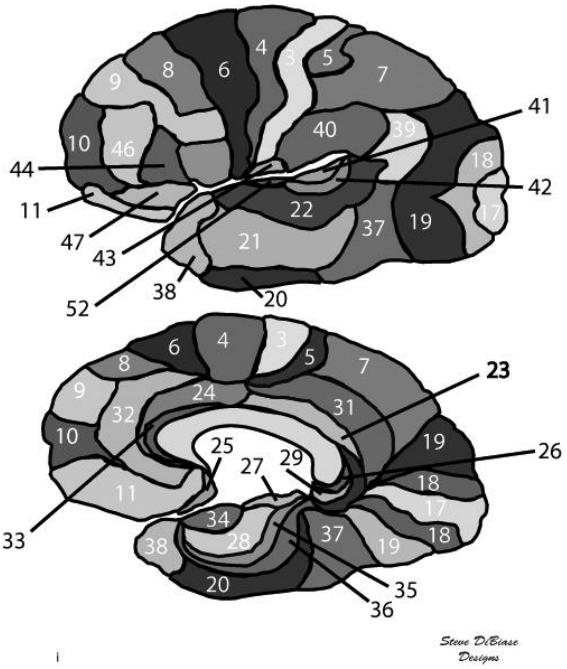

Figure 2: *Brodmann's cytoarchitecture of the brain; reprinted with permission from NET SMART (www.learnstroke.com), Health Outcomes Institute, LLC.*

The subcortex lies directly beneath the cerebral cortex and contains motor and sensory fibres, the basal nuclei, thalami and the lateral ventricles. Afferent sensations travel from the spinal cord through the thalamus and internal capsule and terminate in the cortex, while efferent motor fibres originate in the cortex, travelling through the brain in the opposite direction (9).

The cerebellum

The cerebellum accounts for 10% of the brain's weight. It is separated from the cerebrum by the tentorium cerebelli, while the vermis separates the cerebellum's left and right hemispheres. Like the cerebrum, the cerebellum consists of an outer grey matter, and an inner white matter (9).

The brainstem

The brainstem is comprised of 3 structures – the midbrain, pons and medulla oblongata. It contains ascending sensory pathways, descending motor pathways, cranial nerves (CN) III-XII and vital regulatory centers that maintain homeostasis (12).

Blood supply

While the brain constitutes only 2% of the body's weight, it utilizes approximately 20% of cardiac output. As the brain is unable to store oxygen or glucose reserves, it relies on a constant, uninterrupted supply of arterial blood flow to maintain normal cellular function (13). Autoregulatory mechanisms support continuous flow to the brain, however these processes are energy dependent, and in states where the brain is deprived of oxygen and glucose, autoregulation fails and passive vasorelaxation results (14).

The anterior brain circulation is derived from the common carotid arteries that bifurcate to form the external and internal carotid arteries (ECA and ICA). The ECAs supply blood to the face, neck and scalp, while the ICAs ascend to the brain. At the circle of Willis (COW) the ICAs terminate and give rise to the anterior cerebral arteries (ACA), the middle cerebral arteries (MCA) and the posterior communicating arteries (PComA) (13). While the COW is designed to allow some degree of collateral blood flow in the case of a vessel occlusion, only approximately 50% of the population has an anatomically complete circle; hypoplastic or atretic segments are common. (*Figure 3*)

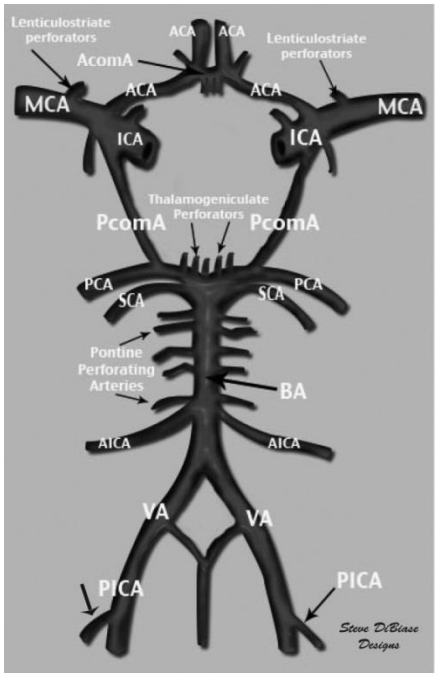

Figure 3 – *Arterial blood supply to the brain; reprinted with permission from NET SMART (www.learnstroke.com), Health Outcomes Institute, LLC.*

The MCAs supply the lateral portions of the frontal and parietal lobes, the superior aspects of the temporal lobes, and part of the occipital lobes. Small perforating arteries extend from the main MCA trunks providing blood flow to much of the subcortical region, including the basal ganglia (13). The majority of ischaemic strokes involve the MCAs (15). The two ACAs, joined by a single anterior communicating artery (AComA), supply the rostral and medial surface of the frontal and parietal lobes. The ophthalmic arteries (OA) derive from the ICAs, and supply the optic nerves and eyes, while the PcomAs connect the anterior circulation to the posterior circulation forming the COW (13).

The vertebral arteries (VA) supply the brain's posterior circulation, they enter the cranial vault through the foramen magnum, and fuse at the level of the pons to form the single basilar artery (BA). At its distal tip, the BA divides to form the posterior cerebral arteries (PCA), which provide arterial flow to the temporal and occipital lobes (*Figure 3)*. The VAs and the BA give off numerous arterial branches and perforating arteries to the cerebellum and the brainstem, including the posterior inferior cerebellar arteries (PICA), the anterior inferior cerebellar arteries (AICA), and the superior cerebellar arteries (SCA) (9).

MECHANISM OF STROKE

Strokes are categorized by aetiology: ischaemic or haemorrhagic. Ischaemic strokes can be further divided into thrombotic (large artery atheroma), cardioembolic, small vessel (lacunar), stroke due unusual cause(s), or cryptogenic (unknown cause) (16). Haemorrhagic strokes are classed as intraparenchymal or subarachnoid haemorrhage. Stroke incidence varies with race; in Western countries ischaemic strokes account for 80% of all presentations, while the incidence of haemorrhagic strokes is much higher in African Americans, Hispanics/Latinos, and most of all, Asians who carry the highest incidence of aneurysmal subarachnoid haemorrhage (aSAH) (17).

Transient ischaemic attack (TIA)

A TIA is sometimes called a "mini-stroke", however unlike a stroke, the patient experiences complete resolution of symptoms typically within minutes (18). About 30-50% of patients originally diagnosed with TIA are shown to have small infarcts on magnetic resonance imaging (MRI) despite resolution of all neurologic symptoms (19). A TIA is a significant risk factor for future stroke, underlying serious vascular dysfunction. As many as 20% of TIA patients go on to have a stroke within 3 months, more than half of these occurring in the first 48 hours (18). Scoring systems, such as the ABCD2 score, categorize TIA patients into high risk and low risk for a future stroke (*Table 1*). High scores (6-7) carry an 8.1% chance of stroke occurrence within the next 2 days, medium scores (4-5) have a 4.1% risk, while low scores (0-3) carry only a 1% risk (18). Rapid determination of the TIA mechanism, supported by targeted secondary prevention are key to preventing future stroke.

Clinical criteria		Score
Age	≥ 60 years	1
	< 60 years	0
Blood Pressure	≥ 140/90	1
	< 140/90	0
Clinical features	Unilateral weakness	2
	Speech disturbance without weakness	1
	Other	0
Duration	≥ 60 minutes	2
	10-59 minutes	1

	< 10 minutes	0
Diabetes	Yes	1
	No	0

Table 1: *ABCD2 score used to grade severity and risk of stroke in patients with transient ischaemic attack.*

Ischaemic stroke

An ischaemic stroke is the result of reduced blood flow either due to an intracranial or extracranial occlusion or stenosis. *Thrombotic stroke*, also referred to as *large artery atheroma*, is associated with risk factors for atherosclerosis, including hypertension (HT), diabetes, smoking, and hypercholesterolemia (20). Endothelial damage and plaque development narrows the artery and changes blood flow dynamics, turbulent flow may further damage the fragile vessel wall (13). Plaque ulceration or rupture results in fibrin and platelet aggregation and thrombus formation, and may cause an artery-to-artery embolism. Depending on the degree of the stenosis, patients may experience a TIA prior to their thrombotic stroke; small clots may temporarily produce symptoms before being auto-lysed by the body, or temporary reductions in blood pressure (BP) may see flow distal to the stenosis reduced to critical levels. Therefore, investigation using vascular imaging is particularly important in the workup.

Lacunar stroke, also called *small vessel* stroke, is a thrombotic stroke that occurs in the small perforator arteries which supply the subcortical regions of the brain and brainstem, and accounts for approximately 25% of all ischaemic strokes (21). The perforating arteries have a very small caliber (0.5mm or less), so the endothelial damage does not have to be extreme for the vessel to completely thrombose (16), and due to their size, vascular imaging will not show an occlusion. While the exact pathogenic mechanism of lacunar strokes is not entirely certain, inflammatory endothelial dysfunction with blood brain failure, significantly damaging vessel walls and stifling arterial flow has gained current acceptance (16). HT is the primary associated risk factor, along with diabetes, hypercholesterolemia and smoking. Despite the small area of infarction, up to 30% of patients can be left dependent following a lacunar stroke (21).

A *cardioembolic stroke* results from emboli that have developed in, or traveled through the heart. The most common pathogenic mechanism is atrial fibrillation (AF), which accounts for approximately 20% of all strokes (22). Other mechanisms include: valvular heart disease, left ventricular dyskinesis, acute myocardial infarction, and even venous thromboembolism (VTE) with embolic transfer through an intracardiac right-to-left shunt from atrial septal defect or patent foramen ovale (16, 23). While the use of anticoagulants helps reduce the risk of emboli formation (23), it is not a fail-safe guarantee. As a cardioembolic stroke is not the result of a long-term atherosclerotic process, there is no ability for collateral arterial development, therefore such strokes may result in devastating infarction and subsequent disability (22).

Unusual processes such as vessel dissection, hypercoaguable blood, sickle cell disease and vasculitis can also cause ischaemic strokes. However the odds of a stroke occurring from these, or other unusual mechanisms, is less likely, therefore thrombotic and embolic stroke are generally ruled out before pursuing other aetiologies. The term *cryptogenic* is used to denote "no identifiable cause for stroke," but should only be selected when an exhaustive work up has ruled out all other possible causes (20).

Case study 1 Part A: Julie is a 48 yo divorced woman with 3 grown children, one of whom lives with her in their rental apartment. Julie is overweight with a 10 year history of type II diabetes and HT both controlled by medication. Two hours ago after coming back from the local shop Julie's daughter found her mother sitting in her chair and leaning to one side, unable to speak coherently and weak

down the right side of her body. This episode lasted for at least an hour, but then resolved by the time the ambulance arrived. Her BP taken by ambulance personnel = 150/90, HR 85 regular, T 36.6, RR, 16.

1. *What is Julie's ABCD2 score?*
2. *What is Julie's risk for a stroke in the next 2 days?*
3. *As the stroke team manager what are the immediate actions that should be taken?*

Haemorrhagic stroke

Haemorrhagic stroke subtypes include intraparenchymal (IPH) and subarachnoid haemorrhage (SAH). SAH is most commonly aneurysmal (aSAH), but it can also occur secondary to IPH, as blood from the hematoma spreads across the surface of the brain. Following an ischaemic stroke, patients may also develop a haemorrhagic transformation of the infarct; a result of fragile vessels leaking blood within the infarct zone (24). Exact rates of haemorrhagic transformation are unknown as most cases are asymptomatic. Symptomatic haemorrhagic transformation causing clinical deterioration (generally defined as a large parenchymal haematoma [type 2] in combination with a 4 or more point worsening on the National Institutes of Health Stroke Scale [NIHSS] is associated with increased mortality (24, 25). While anticoagulation and thrombolytic therapy can increase the likelihood of hemorrhagic transformation, the rates of a symptomatic intracerebral haemorrhage (sICH) following thrombolytic therapy is low, approximately 3-6% worldwide (8, 24-27).

<u>Intraparenchymal haemorrhage (IPH)</u>

An IPH is caused by bleeding into brain tissue as the result of an arterial rupture, and accounts for approximately 10% of stroke cases. The most common cause of an IPH is uncontrolled HT (17, 28). (*Figure 5*). The small perforating arteries are the most vulnerable to rupture, as they receive the highest in-flow pressures, therefore hypertensive IPH's are most commonly found in the subcortical regions of the brain (17, 29). Approximately 14-38% of hypertensive IPH's continue to expand within the first 24-hours, with the potential to increase in size between 20-30% (28). Less common causes of IPH include ruptured vascular malformations and aneurysms, bleeding disorders, trauma, vasculitis, alcohol and drug abuse (especially cocaine and methamphetamine) and amyloid angiopathy. Amyloid deposits are associated with dementia in the elderly, and are classically located in the superficial cortical areas of the brain. It is thought that amyloid deposits weaken the arterial layers predisposing them to breaking (29).

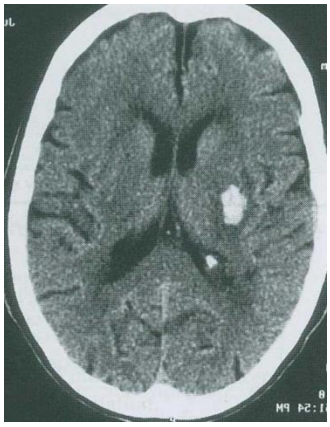

Figure 5: *Left basal ganglia intraparenchymal haemorrhage (IPH); reprinted with permission from NET SMART (www.learnstroke.com), Health Outcomes Institute, LLC.*

Damage to brain tissue in an IPH occurs through numerous mechanisms. Initially the space occupying effect of the haematoma exerts compression forces and raises ICP; a mid-line shift may occur if the haematoma is large. The blood components are toxic to the brain tissue, causing cellular destruction, ischaemia and the breakdown of the blood-brain barrier, thereby initiating secondary

injury through vasogenic cerebral oedema. Lastly, tissue distal to the rupture may be deprived of blood flow, creating additional ischaemic brain injury (17, 29). Common locations for an IPH include:

1. *The basal ganglia*: Most common site, resulting from rupture of the lenticulostriate perforators derived from the MCAs;
2. *The thalamus*: The thalamogeniculate perforators derived from the PCAs and PComAs;
3. *The pons*: paramedian pontine perforators derived from the BA;
4. *The cerebellum*: The penetrating branches of the PICA and AICA; and,
5. *The cortical regions of the brain*: usually the result of amyloid angiopathy associated with abnormal penetrating arteries, or occasionally an MCA aneurysm rupture (29).

While a small IPH from a single penetrating vessel may produce mild stroke symptoms, a massive IPH around the vital centers in the brainstem can result in a life-threatening situation (29, 30), and is commonly associated with a severe headache, vomiting, and altered levels of consciousness including coma, pupil alterations and haemodynamic instability, as well as hemisensory and hemimotor changes. IPH's can extend into the subarachnoid space and the ventricular system, creating secondary intraventricular haemorrhage and SAH (28-30).

Subarachnoid Haemorrhage (SAH)

SAH is caused by bleeding from the large arteries within the subarachnoid space. The most common cause is a ruptured aneurysm, which is more common in middle-aged women, with a mean presentation age of 50 years (31). The exact aetiology of aSAH is not entirely understood, but most commonly includes HT causing haemodynamic stress at points of arterial bifurcation, as well as connective tissue disorders, mycotic aneurysms, and genetic familial mechanisms (31, 32). Severe atherosclerosis can also result in fusiform aneurysm development with circumferential breakdown of the entire vessel wall. Aneurysms are most commonly found in the anterior circulation (13, 31). *(Figure 6)*

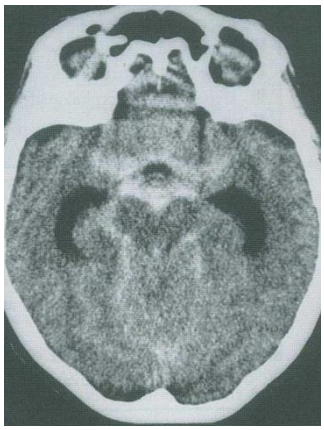

Figure 6: *Computed tomography (CT) scan of diffuse subarachnoid haemorrhage (SAH) with communicating hydrocephalus (large temporal horns of the lateral ventricles); reprinted with permission from NET SMART (www.learnstroke.com), Health Outcomes Institute, LLC.*

Vascular malformations account for only about 1-2% of aSAH's. The most common form is an arteriovenous malformation (AVM); high arterial pressure in the thin walled veins causes weakening of the vessel, increasing the risk for rupture (33, 34). Like aneurysms, AVMs are more likely to be found in the anterior circulation. Approximately 10% of AVM's also have an aneurysm on the feeding artery. It is thought that AVM's are congenital, and they usually become symptomatic in the 3rd or 4th decade of life (33, 34).

SAH may present with stroke-like symptoms, as well as altered levels of consciousness, pupil changes and haemodynamic alterations. Most commonly though, they present with a "worst

headache of my life" scenario, accompanied by meningeal signs such as neck stiffness, vomiting and photophobia due to blood irritating the meninges (31). Injury in aSAH occurs from several mechanisms, including compression of brain tissue with secondary ischaemic injury and raised ICP, as well as secondary ischaemic stroke resulting from vasospasm and communicating hydrocephalus (31, 34).

STROKE LOCALIZATION

Stroke locale can be described by the affected lobe/s (e.g. fronto-parietal stroke), or by vascular territory (e.g. MCA stroke). Clinical localization of stroke symptoms is an essential skill for critical care nurses and physicians, enabling observation of stroke progression or resolution. Additionally, because ischemic strokes are generally not visible on non-contrast computed tomography (NCCT) scan until at least 6-8 hours after symptom onset, clinical localization provides the basis for stroke diagnosis (7, 35).

Cerebral cortex

Frontal Lobes

Major functions of the frontal lobes include voluntary motor function, higher intellectual function and language expression (10). The pre-central gyrus is Brodmann's area 4, (*Figure 2*) also called the motor strip; it extends from the medial longitudinal fissure bilaterally down both hemispheres to the junction of the temporal lobe. The motor strip receives dual vascular supply (*Figure 7*): ACAs supply the medial/superior aspects of the motor strip, while the MCAs supply the lateral regions (10).

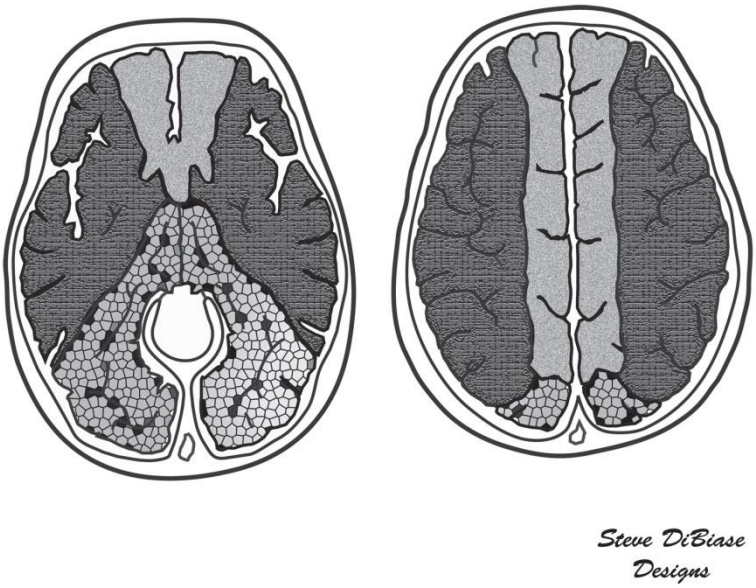

Figure 7: *Arterial distribution of the cerebral cortex (inferior view-left; superior view right); the dark grey areas represent the middle cerebral artery (MCA) territories bilaterally; the light grey areas represent the anterior cerebral artery (ACA) territories bilaterally; the beaded grey areas reflect the posterior cerebral arterial (PCA) territories bilaterally; reprinted with permission from NET SMART (www.learnstroke.com), Health Outcomes Institute, LLC.*

Within the motor strip, the area responsible for the leg movement is within the ACA territory superiorly, while the arms, hands, and face are located laterally in the MCA territory (10). Consequently, an MCA stroke classically produces weakness in the arm, hand, face, tongue, larynx/pharynx. Distal ICA and proximal MCA occlusions can also affect the leg by stifling flow into

the ACA (9). Motor fibres from Brodmann's area 4 travel through the subcortex to the brainstem, where they cross over to the other side in the pyramids of the medulla, producing weakness contralateral to the side of the injury (10, 36).

Brodmann's area 44 (*Figure 2*), also called Broca's area, lies anterior to area 4; damage to this region results in expressive language loss (aphasia). Supplied by the MCA, area 44 most commonly occurs in the left hemisphere, including in left handed people (11). It is important to assess hand dominance in patients who present with a right MCA stroke who also have expressive language loss, since rarely in left handed individuals area 44 will be located on the right. Damage to Brodmann's area 44 will cause difficulty with both written and spoken language. Clinical examination must assess word finding capabilities and fluency of language (37). Dysarthria may also be present due to the proximity to Brodmann's area 4 (36). *(Table 2)*

Brodmann's areas 9, 10 and 11 *(Figure 2)* are supplied by the ACA and lie adjacent to the longitudinal fissure. These cortical areas play a key role in cognition and executive functioning, including orientation, memory, insight, judgement, and arithmetic and abstraction (10, 12). An ACA stroke can result in a patient displaying behavioural changes independent of motor weakness. Changes to cognition may be mistaken for language dysfunction (MCA stroke), therefore thorough clinical assessment and localization is essential (36)

Clinical Findings (sudden onset)	Possible neurovascular territory
Arm and face weakness	Contralateral MCA
Leg weakness	Contralateral ACA
Arm, face and leg weakness	Contralateral distal ICA (supplying both MCA and ACA) or proximal MCA
Loss of language frequency	MCA (usually left)
Cognitive changes	ACA

Table 2: *Localization rules for frontal clinical findings; reprinted with permission from NET SMART (www.learnstroke.com), Health Outcomes Institute, LLC.*

Parietal Lobes

The parietal lobes are the primary sensory lobes of the brain. They also receive dual vascular supply from the ACA's and MCA's (*Figure 7*). Sensory information is sent from the periphery through the thalamus to the parietal cortex. The primary sensory strip lies in the post-central gyrus behind the motor strip, and is represented by Brodmann's areas 1, 2 and 3 (*Figure 2*). The sensory strip distribution parallels the motor cortex with the feet, legs and trunk located superiorly in the ACA territory, while the arms, hands and face are found laterally in the MCA territory (11). Like the motor cortex, the sensory strip is found in both hemispheres, damage results in contralateral symptoms (36).

Brodmann's areas 5 and 7 (*Figure 2*) are supplied by the MCA and are involved in somesthetic association. Assessment involves using double simultaneous stimulation (DSS) to test for neglect or extinction. In DSS testing, patients may be able to detect sensations if they are applied singularly, but may 'neglect' the stroke affected side during simultaneous touch or visual testing (36). The patient may also display difficulty with sensory interpretation, such as stereognosis and graphesthesia, where they are unable to decipher everyday objects by touch alone or determine a number or letter traced on the affected limb (37).

Found most commonly in the left MCA territory, Wernicke's area (Brodmann's 39 and 40) (*Figure 2*) is responsible for receptive language, including language connections with other areas of the brain, such as auditory language in the temporal lobe, memory in the limbic system and expressive language responses in the frontal lobe. A stroke affecting Wernicke's can result in fluent aphasia, where the patient can produce speech but word placement is nonsensical. A large left MCA stroke can affect both language centres, resulting in global aphasia (37).

It is important to note that while isolated parietal lobe damage does not produce motor weakness, a parietal lobe stroke often occurs in association with a frontal lobe stroke due to their shared blood supply, thus motor and sensory changes are often seen together (36). *(Table 3)*

Clinical findings (sudden onset)	**Possible neurovascular territory**
Arm and face numbness (and weakness)	Contralateral MCA
Leg numbness (and weakness)	Contralateral ACA
Arm, face and leg numbness (and weakness)	Contralateral distal ICA or proximal MCA
Loss of receptive language	MCA (usually left)
Sensory neglect	Contralateral MCA

Table 3: Localization rules for parietal clinical findings; reprinted with permission from NET SMART (www.learnstroke.com), Health Outcomes Institute, LLC.

Temporal lobes

The superior aspects of the temporal lobes are supplied by the MCA's (*Figure 7*) while the posterior and inferior aspects are supplied by the PCA's. The temporal lobes have major functions in auditory reception and olfaction (10). Brodmann's area 41 is the primary auditory reception area (*Figure 2*) present bilaterally to supply the brain with sound impulses from each ear. Area 28 (*Figure 2*) located in the hippocampal gyrus, is the primary olfactory center (10) *(Figure 7)*. While temporal lobe damage can result in auditory hallucinations, primary auditory loss is a rare complication, occurring more commonly in a brainstem stroke (12, 36).

Occipital lobes

Supplied by the PCA's, the occipital lobes are the primary visual lobes. Brodmann's area 17 (the primary visual cortex) and 18 (the visual association cortex) (*Figure 2*) are responsible for receiving and interpreting visual images (37) (*Figure 7*). Brodmann's area 18 helps the brain map visual images in terms of spatial awareness, orientation and colour. Visual agnosia may result from an occipital stroke, where the patient can see but lacks the ability to interpret or make sense of what they are seeing (36).

Images travel from the eyes, along the optic nerves to the optic chiasm and the optic tract, before being transmitted to the cortex for processing and interpretation. Monocular vision loss occurs from damage at the level of the retina or optic nerve, whereas binocular defects indicates damage at the chiasm or beyond (36). A homonymous hemianopia is a binocular defect characterized by a loss of vision in one-half of the visual field in both eyes (e.g. vision is lost in the left half of the visual field in both eyes). While a homonymous hemianopia always indicates damage beyond the chiasm, it can result from a large MCA fronto-parietal stroke that damages the visual pathways, as well as from primary occipital cortical damage (38). Clinical assessment will help with stroke localization: pure

visual loss in the absence of other findings occurs in PCA occipital stroke, while the addition of sensorimotor symptoms points to an MCA fronto-parietal stroke. Cortical blindness (double hemianopia) is a rare finding, indicating bilateral PCA strokes, which can occur over time, or as a single severe stroke, such as a top of the BA stroke which reduces flow into both PCA's simultaneously. Diplopia (double vision) is the result of brainstem damage and not occipital lobe damage (11, 36).

Case study 1 Part B: You are about to move Julie for a CT scan when all of a sudden you notice that she is unable to speak and appears to not comprehend you, has complete flaccidity of the right side of her body including face and is staring to the left.

1. *Considering Brodmann's cytoarchitecture of the brain, please describe which areas of the brain have been affected and why?*
2. *What is the likely arterial territory affected by the stroke?*
3. *What is the type of speech abnormality that Julie presents with?*

The subcortex

Subcortical strokes result from damage to small perforator arteries. A subcortical stroke can be small (lacune, single perforator) or large (multiple perforators), and can be asymptomatic or very physically disabling, depending on the exact locale of the stroke (21). While a subcortical stroke will not result in damage to the primary motor or sensory cortices, sensorimotor changes can be present if the thalamus or afferent sensory/efferent motor tracts are affected. To aid stroke localization, pure cortical symptoms such as neglect, aphasia and apraxia will be absent in a subcortical stroke (21, 36). Strokes within the subcortical grey matter of the basal ganglia can result in extra-pyramidal motor dysfunction, such as rigidity, non-fluid muscle tone, reduced speed of actions, tremors or other involuntary movements (10, 12).

The cerebellum

The cerebellum is supplied by the VA's, PICA's, BA, AICA's and the SCA's (36). The cerebellum is responsible for fine motor coordination, tone, posture, balance and equilibrium (12). Cerebellar tests include: tandem gait walking, Romberg's test assessing balance and gait stability and ataxia (assessing the degree of smooth motor control) (36). Ataxia, dysmetria, dysarthria, dysphagia and unsteady gait are all pathological findings and are usually ipsilateral to a cerebellar lesion. Cerebellar strokes can also present with vertiginous symptoms which need to be distinguished from a peripheral vertigo (39).

While the cerebellum is involved in motor *control*, a pure cerebellar stroke does not cause motor weakness or alterations in sensation. However, cerebellar strokes often occur in association with a brainstem stroke due to their shared blood supply. Therefore a clinical presentation of both ataxia or vertiginous symptoms *and* weakness or numbness should raise suspicions of a combined cerebellar and brainstem stroke (36, 39).

The brainstem

The brainstem shares its vascular supply with the cerebellum. The brainstem contains sensory and motor pathways, CN III-XII, and the major control centres of the body (40). Given the spread of cranial nerve distribution throughout the brainstem, stroke symptoms can vary depending on the specific location of the lesion.

<u>The midbrain</u>

The midbrain houses the visual reflex centre for coordinated head and eye movement in response to visual and auditory stimuli, and cranial nerves III (oculomotor) and IV (trochlear). A midbrain stroke can result in extraocular eye movement (EOM) disorders, diplopia, pupillary dilation, changes to the level of consciousness (LOC) and sensorimotor alterations (12, 36, 40).

The pons

The pons houses cranial nerves V (trigeminal), VI (abducens), VII (facial) and some of VIII (vestibulocochlear), as well as the apneustic and pneumotaxic respiratory centres (10, 12, 40). A pontine stroke can cause changes to the respiratory pattern, a decreased LOC, sensorimotor changes and EOM disorders. Diplopia can result from a lack of visual fusion caused by damage to the extraocular muscles and nerves, particularly CN's III and VI (12).

The medulla oblongata

The medulla is continuous with the spinal cord. Voluntary motor fibres decussate (cross over) in the pyramids of the medulla (40). The medulla houses cranial nerves: VIII (vestibulocochlear), IX (glossopharyngeal), X (vagus), XI (spinal accessory) and XII (hypoglossal). It also contains the cardiac and vasomotor centers, as well as an additional respiratory centre (12, 40). Medullary stroke can cause sensorimotor dysfunction, haemodynamic instability, altered LOC, and speech and swallowing difficulties (36).

The basilar artery (BA)

It is important to make special mention of the BA - it supplies the cerebellum and the brainstem and gives off the PCAs, therefore occlusion can produce significant variation in symptoms, including: sensorimotor alterations, vertigo, ataxia, nystagmus, clumsiness, hiccups, shivering, dysarthria, diplopia, cortical blindness, dysphagia, quadraparesis and reduced LOC, including coma and locked-in syndrome (41, 42). A BA stroke is the most frequently misdiagnosed of all ischaemic stroke presentations, often mistaken for a cerebral stroke, peripheral ear disorder, an intracerebral haemorrhage, or primary respiratory disorders (36, 41).

Clinical localization rules that guide stroke differentiation:

1. Patients with hemisensory or hemimotor loss that is extensive (face, arm and leg) and all on the same side, will have a lesion within either the cortex, subcortex or the upper brainstem
2. Patients who present with *bilateral* symptoms, that is, cranial nerve symptoms on the opposite side to sensorimotor changes in the extremities, will have a lesion at the midpoint of the pons or lower
3. Uncommon findings such as auditory loss, vertigo, extra-ocular movement (EOM) disorders, hiccups and shivering are usually associated with a brainstem stroke
4. Any sudden loss of consciousness that is not caused by a haemorrhagic stroke is suspicious for a brainstem (BA) stroke

STROKE MANAGEMENT

The principles guiding acute stroke management aim to optimize patient functional status and reduce disability and death, through rapid identification and diagnosis of stroke, delivery of disability

reducing treatments, avoidance of complications, determination of stroke pathogenic mechanism and risk factors, and provision of targeted, individualized secondary prevention strategies. In acute ischaemic stoke, the first priority after emergent diagnosis is arterial recanalization to restore blood flow, whereas in haemorrhagic stroke, the first priority is to prevent haemorrhagic expansion (7, 43).

Hyperacute stroke management

Emergency stroke care varies internationally, but most countries offering hyperacute stroke services will have some form of pre-hospital emergency service to assess, stabilize and transport acute stroke patients to hospitals to a Stroke Centre (43).

Pre-hospital stroke scales, such as the Los Angeles Pre-hospital Stroke Scale (LAPSS), the Cincinnati Pre-hospital Stroke Scale (CPSS) and the Melbourne Ambulance Stroke Scale (MASS) are often used to assist paramedic diagnosis of stroke. Both MASS and LAPSS trained paramedics have been proven to be highly accurate in diagnosing stroke, and by using pre-hospital stroke protocols, they are instrumental in reducing door-to-treatment times, and increasing the number of patients eligible for reperfusion therapies in the Emergency Department (ED) (44-47).

Not all patients arrive via ambulance, so the triage nurse plays a vital role in recognizing an acute stroke and activating the correct stroke protocols (46, 48, 49). These will vary between facilities, but most stroke centres accept the 3 - 4.5-hour time window for intravenous alteplase (IV t-PA) treatment, while others may use extended hours to incorporate intra-arterial (IA) procedures, including endovascular clot retrieval (ECR) and/or clinical trial enrollment (26, 48, 50). The Emergency Severity Index (ESI) is a common triage prioritization system used in ED's. Acute stroke patients should be allocated a category 2, i.e. they "should not wait to be seen" by a medical provider; however, some stroke patients with altered LOC or respiratory/haemodynamic compromise may be an ESI category 1 meaning they are at "imminent risk for death." Regardless, stroke patients should be immediately assessed both clinically and radiologically, and all relevant treatments commenced in a high acuity area of the ED (51).

<u>Hyperacute ischaemic stroke management</u>

Thrombolysis treatment with IV t-PA is the gold standard treatment for acute ischaemic stroke, but its use is limited by both time and patient selection parameters (8, 27). IV t-PA is approved by governmental drug regulation agencies for administration at either 3 hours (United States, Canada, Croatia, and Moldova) or 4.5 hours (Europe [excluding above], Asia, South America, South Africa, Israel, and Australia) from symptom onset or the time the patient was last seen normal, although most providers give the medication out to 4.5 hours regardless of governmental regulations (50, 52). Thrombolysis therapy is not without risk, however contemporary rates for systemic bleeding and sICH are quite low (3-6%), even when alteplase is used out to 4.5 hours from symptom onset; this is especially true at Stroke Centres with high alteplase treatment volumes (8, 27). Patient selection should include careful review of neuroimaging to exclude haemorrhagic stroke or structural lesions (tumors, AVMs, aneurysms), and the clinical exam should reveal findings consistent with a neurovascular territory. Most advanced centres do not wait for laboratory blood results before commencing treatment, except in patients with specific histories that indicate potential abnormalities (8, 26, 27, 53). International randomized placebo controlled trials and phase IV effectiveness studies have consistently shown that patients who receive treatment with alteplase have a 30% greater chance of having minimal to no neurological disability by 3 months, with no increased risk of death, making alteplase the most important first step in managing acute ischaemic stroke (26, 27, 54).

Almost 2 million neurons die each minute in a large vessel stroke, and every 15-20 minute reduction in time to treatment gains the patient an extra month of disability-free life and reduces the odds of mortality by 5% (48, 55, 56). Traditionally, international recommendations have called for IV t-PA to be administrated within 60 minutes of patient arrival to hospital (7, 57). However, the benefit of alteplase treatment is frontloaded, with almost 3 times improved odds for minimal to no disability at 3 months when treatment is commenced within the first hour of stroke onset; consequently many large volume centres now aim for a door-to-treatment time of less than 30 minutes to maximise patient outcomes (8, 26, 27, 54). Strategies to improve door-to-treatment times include, the use of highly educated and specialized acute stroke advanced practice nurses, "Code Stroke" teams, and standing orders for many standard acute stroke processes, including blood tests and NCCT scans (58-62).

Specific recommendations to achieve rapid IV t-PA commencement include: immediate assessment in line with ESI triage Category 1-2, quickly ascertaining the history; blood work drawn and sent to the lab; vital signs and a 12-lead electrocardiogram obtained (7, 63). The National Institute of Health Stroke Scale (NIHSS) is an internationally used and validated stroke scale, which quantifies stroke disability, ranking stroke symptoms with scores of 0 (no disability) to 42 (severe disability). The NIHSS is considered standard of care in most countries for use by both stroke nurses and physicians, and it should not be substituted for simpler scores such as the Glasgow Coma Scale (GCS) which has no validity in ischaemic stroke (64, 65).

A NCCT scan should be commenced within 25 minutes of the patients' arrival. A NCCT is highly sensitive to blood and can be completed rapidly, making it the neuroimaging test of choice allowing the team to quickly rule out haemorrhagic stroke (7, 66). In the hyperacute phase of ischaemic stroke, it is expected that the NCCT will either be normal or have only very subtle early signs of infarction, such as slight blurring of the grey-white matter boundaries, early loss of sulcal effacement, or a hyperdense artery sign (7). Additional CT modalities such as a CT angiogram (CTA) and CT perfusion (CTP) are not necessary to make an alteplase decision, but may be useful in the overall determination of stroke mechanism. In particular, CTA will differentiate large versus small artery occlusion which will determine the need for advanced therapies, including ECR; and CTP may offer information that makes the patient eligible for treatment beyond the standard alteplase 4.5-hour window (67, 68)

When NCCT is positive for haemorrhage, CTA can also provide useful information, including diagnosing aneurysms or AVM's, as well as documenting ongoing bleeding (28, 31, 69). While MRI is more sensitive to early ischaemic changes, it is usually impractical in the management of acute ischaemic stroke due to both unavailability for emergency scanning and longer scanning times (7, 52). All brain scans must be rapidly interpreted; blood tests can be interpreted as they become available, but without any history of anticoagulation, these take on less importance when determining alteplase eligibility.

High volume stroke centres aiming for treatment times of less than 30 minutes cut out many of the above steps, or perform parallel tasks, beginning with calling a "Code Stroke" immediately upon pre-hospital notification, gathering the stroke team to the ED. The stroke team, rather than the ED team perform the initial assessment and history taking. Haemodynamically stable patients with no other immediate care needs are taken "direct to CT", the stroke team reads the patient's CT scan in real-time on the CT console and an immediate treatment decision is made. Alteplase is drawn up in the CT control room and started while the patient is still on the CT table, a CTA can then be obtained once the alteplase drip is running (58, 60, 62).

Stroke is a severely disabling disease; therefore, the decision to treat with alteplase should not require a written informed consent, much like emergency surgery following trauma or provision of reperfusion therapy in an acute myocardial infarction. However it is important, when possible, to explain the risks and benefits of alteplase treatment to the patient and/or family and to document their assent to treatment. The alteplase dose is weight-based, but unless the hospital bed or ED stretcher is equipped with a scale, it is not practical to weigh the patient; instead, the patient or family are asked to provide a weight estimate, or the stroke team will make a 'best guess' of the patient's weight. Interestingly, lack of measuring weight has not been shown to decrease the safety of alteplase treatment (70). Alteplase is administered at a dose of 0.9mg/kg not to exceed a total dose of 90 mg; 10% of the total dose is given as a bolus, followed by a 60-minute infusion of the remaining 90% of the total dose.

Uncontrolled HT is the most common factor associated with the development of sICH following t-PA. Therefore it is vital that any deviations to the specified BP parameters are acted upon quickly with intravenous antihypertensive agents (7). However, it is important not to lower the BP too far because reduced arterial flow through an occlusive lesion may worsen the ischaemia (7, 71, 72). Many alteplase protocols advise against using non-invasive oscillometric blood pressure (NIBP) cuffs after IV t-PA, advocating instead for the use of manual sphygmomanometers, as there is concern that the degree of mechanical compression caused by an NIBP machine may cause bruising and haematoma development in the arm. However, there are no studies that have documented actual soft tissue injury/bruising occurring from NIBP in alteplase treated patients, so this risk is likely unfounded. Because alteplase alters normal blood coagulation, unnecessary invasive procedures (blood draws, nasoenteric tube or urinary catheter insertion) should be avoided for the first 24 hours post alteplase unless absolutely necessary.

Hyperglycaemia in the acute phase of a stroke has been shown to worsen neurological outcomes, and should be promptly treated with insulin to maintain near-normal blood glucose between 4.5-6.0 mmol/L (80-110mg/dL) (7, 52, 72-74). Hyperthermia is also associated with poorer outcomes, due to increased metabolic demands on an already taxed brain, and temperatures above 37.5°C (99.5°F) should be treated with paracetamol (acetaminophen) per os if the patient has passed a swallow screen, or per rectum/intravenously in the case of dysphagia (7, 72, 74, 75). Acute stroke unit patients who had their temperatures and blood sugar levels regularly checked and treated, and who were kept nil orally until safe swallowing were documented, were found to have a 15.7% improvement in 3-month death and dependency rates, demonstrating that good nursing care can positively impact patient outcomes (74).

Up to 22% of patients in the first 24-hours experience neurological deterioration as a result of arterial re-occlusion (76). Therefore, patients should be carefully assessed using the NIHSS, and an urgent NCCT scan should be performed on all patients who have a neurological deterioration (7). Patients who develop a sICH may need reversal of alteplase with cryoprecipitate, however most patients developing sICH do not undergo reversal as the damage is well advanced prior to when initiation would be possible. Patients who experience a vascular re-occlusion may be eligible for ECR (7). In patients with large arterial vessel occlusion (LVO), placing the head of bed (HOB) at zero degrees has been shown to increase blood flow by 20% to ischaemic regions of the brain to stabilize the patient while other potent therapies (alteplase and/or ECR) are commenced (46). The negative HeadPoST study investigated if this practice resulted in improved functional outcomes at 3 months, however the study randomized primarily small vessel (lacunar) strokes, and the selection of a 3 month outcome based on head positioning alone was inappropriate (77, 78). The ZODIAC Stroke study is examining if zero degree positioning can promote stability in hyperacute LVO patients – the

only patients ever shown to benefit – using a proximal clinical endpoint appropriate for a head positioning rescue therapy (www.ZODIAC-Stroke.com).

Thrombectomy or ECR is highly effective in achieving minimal or no disability at 3 months in patients with a demonstrated large vessel occlusion, even up to 16-24 hours post stroke onset in selected patients, but like alteplase, it has been proven to be most successful when commenced as early as possible (79-86). Unfortunately, this procedure is not widely available, with few specialist centres offering this service worldwide. Eligible patients should still be treated with IV t-PA, and initiation of ECR must not be delayed by waiting to determine if alteplase treatment was effective. A number of devices are approved for use throughout the world, but only retrievable stents (stentrievers) have shown efficacy at achieving a difference in functional outcome by 3 months (86). Similar to a coronary angiogram, a femoral artery approach with light sedation is usually used, although some patients may require intubation for their own safety during the procedure. Nursing care of the patient having an ECR includes sedation and airway management, weaning and extubation procedures if the patient was intubated, haemodynamic monitoring, neurovascular observation of the distal extremity, and observation for haematoma or bleeding at the femoral site, along with care of intra-arterial sheaths that may be left in post-procedure. Similar to all ischaemic stroke patients, ongoing neurological assessments must be documented using the NIHSS (63).

Hyperacute haemorrhagic stroke management

Like an ischaemic stroke, there are limited hyperacute stroke treatments available for haemorrhagic stroke. Some patients may be appropriate for surgery, but in most instances, treatment is medical management of the symptoms and BP. Not all patients are suitable candidates for neurosurgery; haematoma size (too large and the damage is too extensive, too small and the risks of surgery outweigh the benefits), location (superficial cortical regions), and the patient's pre-morbid health are key criteria. Unfortunately, in most cases, acute surgical management may be lifesaving, but ultimately does not negate the level of permanent disability (28, 87).

In the case of aSAH, endovascular occlusion of aneurysms or AVM's by coil or liquid embolic agent, or surgical clipping may be indicated to reduce the initial size of the structural lesion, permanently occlude it, and prevent re-bleeding (88). If SAH is clinically likely, yet is not apparent on NCCT, it may be necessary for the patient to undergo a lumbar puncture to assess for blood in the CSF and confirm the clinical diagnosis (88). Close monitoring for signs of ongoing bleeding, development of hydrocephalus and raised ICP are essential for best patient outcomes in a haemorrhagic stroke. Aggressive BP reduction has been proposed as a method to limit haematoma growth, especially in hypertension-induced IPH's, although a phase III clinical trial showed no difference in 3 month outcomes (INTERACT-2); another phase III trial (ATACH-2) was stopped early due to futility (89, 90). Despite this, most stroke specialists agree that some degree of BP control is warranted. Specific BP aims will be determined by local protocols, as will drugs of choice, but intravenous agents that allow good control without causing hypotension or rebound HT are recommended (43). Coagulation status must be determined quickly, and any coagulopathy reversed (30, 91). In particular, warfarin related coagulopathies are associated with significant haematoma expansion and should be urgently treated with vitamin K and cryoprecipitate or prothrombin complex concentrate (30); fresh frozen plasma is usually discouraged or used as last resort, because of the large volume that would be necessary to reverse coagulopathies. Factor VIIa has also been used, but is expensive, often has limited availability, and has not been shown to improve 3-month outcomes (30, 92). Current trials are looking at other agents that can be used to reverse coagulopathies that may be less expensive and easier to administer, with possibly better outcomes (69).

Hydrocephalus can develop if the ventricles or the arachnoid villa become obstructed, especially as a result of a SAH; this may necessitate the use of a ventricular drain to prevent a dangerous rise in ICP

(30). Like any pressure line, a ventricular drain/ICP monitoring system should be leveled and zeroed appropriately, in this instance, to the foramen of Monro (43). Nursing care should include maintaining the patient with the HOB elevated to 30°, aiding venous drainage through proper head positioning and reducing stress including noise and workload. Close observation of the pressure line/drain and monitoring of neurological condition are crucial as catheter blockages are not uncommon and can result in a sudden clinical deterioration (43). While initially designed to be used for ischaemic stroke, the NIHSS is a useful tool in haemorrhagic stroke patients with focal deficits, providing significantly greater information on the patient's clinical status than the GCS which only assesses consciousness (64).

In cases of a massive haemorrhagic stroke where the prognosis is incredibly poor, it may be more appropriate that the patient is considered for a palliative approach rather than be subjected to lengthy and ultimately futile medical investigations and treatments. The patients' wishes (if known) should be taken into account, this needs to be sensitively discussed with the patients' family, ideally in conjunction with a palliative care team (43).

Case study 2 Part A. John is a 65 yo recently retired policeman. He has been bought to the ED by paramedics with his wife present. John is unconscious, BP 195/100, HR 62, T 37.5, RR 20 and labored. John's wife noted that he went to bed after dinner having complained of a headache, when she checked on him 2 hours later he could not be roused and had vomited.

1. *As Johns nurse, what are the immediate care priorities in this hyper acute phase?*
2. *What diagnostic tests might you need to prepare for to receive a rapid and accurate diagnosis of John's condition?*
3. *What medications, if any are likely to order at this stage, why?*

Mobile Stroke Units (MSU)

A recent introduction to acute stroke management has been the Mobile Stroke Unit (MSU) *(Figures 8 and 9).* The first MSU was launched in Homburg, Germany in 2008, and since then more than 20 MSU's have been activated worldwide. While the exact design and operations differs between vehicles, a MSU is a specialised ambulance that contains an on-board CT-scanner and carries acute stroke personnel in addition to ambulance paramedics (93). The MSU is able to assess, diagnose and treat acute stroke patients in the pre-hospital setting. While studies in this area are ongoing, preliminary data has shown significant reductions in treatment times and increased numbers of eligible patients treated, including within the first 60-mins of stroke onset (the "Golden Hour"), as well as improved access to comprehensive stroke centres for patients requiring neurosurgery or ECR, which reduces the need for inter-hospital transfers. It is hoped that by treating patients earlier, MSU's will help reduce death and disability rates for stroke patients, especially as they are much more likely to treat patients within the Golden Hour than hospitals are when patients are transported routinely (94-97).

Figure 8: *University of Tennessee Memphis Mobile Stroke Unit equipped with 16-slice Siemens Somatom Scope® scanner and head/neck CTA autoinjection system; with permission from University of Tennessee Health Science Center at Memphis, Mobile Stroke Unit*

Figure 9: *Melbourne Mobile Stroke Unit equipped with an 8-slice Samsung Ceretom® scanner; with permission from The Melbourne Brain Centre at The Royal Melbourne Hospital, Mobile Stroke Unit*

Ongoing acute stroke management

Once the hyperacute phase of stroke management is organized and underway, the focus shifts to the ongoing care required for the remaining duration of the patient's hospital stay. Similar to a coronary care or intensive care unit, an Acute Stroke Unit (ASU) is a geographically discreet area or ward, staffed by a multidisciplinary team of stroke experts who work together for the benefit of the patient. Patients treated in an ASU are more likely to be alive and independent 12-months post stoke compared to patients treated in a standard medical ward. This benefit has been shown across all stroke types and is irrespective of any hyperacute treatment the patient may have received; it is therefore vital that all stroke patients are admitted to an ASU as early as possible (98-102).

Most of the care initiated in the ED will continue in the acute stroke unit (ASU), including BP, glucose and temperature management. New priorities will also be set for both ischaemic and haemorrhagic stroke, including prevention of complications, discharge planning, determination of aetiologic mechanism, commencement of secondary prevention targeting the aetiology, and education, all in an attempt to reduce the likelihood of a further stroke (43).

To determine aetiology, the patient will undergo numerous investigations. Large vessel imaging (if not already performed in the hyperacute care phase), will be needed to look for stenoses of the major extra- and intracranial arteries in ischaemic stroke, particularly the ICA's, which may require surgical intervention to remove plaque by carotid endartectomy (103). In the case of IPH, vascular imaging is also important to determine mechanism and ongoing bleeding. In both ischaemic and haemorrhagic stroke, MRI is often used to measure the final outcome of stroke interventions and aid in determining stroke location and mechanism (104). To detect AF, cardiac monitoring is usually used for at least the first 24 hours, and ongoing monitoring may be ordered as an outpatient if AF is suspected but has not been seen during the in-patient stay (105). An echocardiogram (transthoracic and/or transoesophogeal) may be ordered to look for underlying cardiac and valvular disease, including a previously undetected right-left shunt associated with atrial septal defect or patent foramen ovale; this is also important in IPH patients because underlying poorly controlled HT may have caused ventriculomegaly and left ventricular remodeling. In ischaemic stroke patients with no other clear cause of stroke, additional blood work may be ordered to detect hypercoaguable conditions (106), and in a small number of cases, the cause may never be found.

Patients need to have regular, serial neurological assessments performed to detect changes in their clinical condition. Deterioration can be the result of a variety of causes, including haematoma expansion in haemorrhagic stroke, haemorrhagic transformation of an ischaemic stroke, vascular re-occlusion, and most commonly evolution of the existing infarction (7). In aSAH, deterioration can also be the result of vasospasm which usually peaks between days 5-7 post rupture, and may produce delayed ischaemic injury causing a secondary ischaemic stroke (31). Vasopspasm is best detected using non-invasive transcranial Doppler (TCD) monitoring. Repeat brain scans should be urgently ordered if deterioration occurs (7, 31).

BP control continues in the ASU but BP aims may need to be adjusted to maintain flow through existing extracranial or intracranial stenoses, or through spastic arterial segments in aSAH. Intravenous agents initiated while the patient was nil per os can be changed to oral agents as appropriate, or administered via enteral tubes in patients with dysphagia. It is often necessary to combine multiple antihypertensive agents to achieve adequate control, and each agent should be added slowly and adjusted to effect. Consideration should be given to the mechanism of drug action, taking into account concurrent renal and cardiac disease, and even race, as studies indicate that certain types of antihypertensives may be more effective in different races (e.g. calcium channel

blockers may be more effective than ACE-inhibitors in hypertensive black patients due to lower rates of renin-induced HT) (7, 43, 107)

Regardless of whether the patient is having an ischaemic or haemorrhagic stroke, blood sugar levels should continue to be carefully monitored and managed in the ASU, ideally maintaining normoglycaemia (between 4.5-6.0mmol/L or 80-100mg/dL), but certainly less than 10mmol/L (180mg/dL). Agents selected should be determined by the degree of glycemic control needed, with patients that present with extremely poor control considered for insulin management (7, 30, 74). It is essential to continue to closely monitor temperature, as hyperthermia is associated with poor neurological outcomes post stroke, additionally a temperature may also herald an infectious process, such as an aspiration pneumonia, which can worsen mortality rates (7, 72, 74). To reduce the risk of aspiration, the patient should be kept nil per os until they have been properly assessed and cleared for oral intake with either an evidence-based dysphagia screening tool, or formal evaluation by the speech-language pathology team (74, 108). It is important that these assessments are conducted as early as possible in the patient's hospital stay, as even 24 hours without nutrition may negatively impact recovery, especially in elderly patients with premorbid malnutrition (43). Be aware that patients may have already aspirated prior to arrival at hospital, particularly those who were found collapsed as a result of their stroke. Saliva aspiration is possible, even in patients who are nil per os, therefore exquisite pulmonary assessment and care are high priority. Patients should be maintained side-lying and deep breathing and coughing exercises should be encouraged to reduce the risk of chest infection, and nursing assessments should include monitoring for changes to respiratory function, such as respiratory rate, pattern of respirations, breath sounds and gas exchange, as well as pulse oximetry values (43).

Sleep apnea is associated with stroke in 30-70% of cases but it is unclear if the aetiology is from a central or obstructive cause, or a combination of both (109). Patients with suspected sleep apnea should have sleep studies performed so appropriate therapy can be instituted. Sleep apnea can have a significant impact on the ischaemic brain following stroke. Under normal physiological conditions, an apneic period will raise the level of carbon dioxide (CO_2) in the brain, resulting in arterial vasodilation in healthy brain regions, however in ischaemic regions, arteries are already passively maximally dilated (110). Termed "Reversed Robin Hood Syndrome (RRHS)", vasodilation in healthy regions of the brain ultimately "steals" blood flow away from the already maximally dilated ischaemic brain thus worsening ischaemia in the area affected by stroke (110). Treatment of the sleep apnea with non-invasive modes of ventilation, such as continuous positive airway ventilation (CPAP) or bi-level positive airway pressure (BiPAP) reduces arterial steal maintaining consistent arterial flow rates though the brain (109).

Protocols for patient care after IV t-PA often call for bed rest for the first 12-24 hours to reduce the risk of a major bleed in the event of a fall, and early aggressive mobilization may place patients at risk for worse 3 month outcomes (111). However, once ischaemic and haemorrhagic stroke patients are haemodynamically stable without fluctuating stroke symptoms, progressive mobilization and assessment of physical capabilities by physiotherapists and occupational therapists is essential to minimize complications, such as venous thromboembolism (VTE) development, physical deconditioning, and skin breakdown (7, 52). Even while the patient is in bed, passive range of motion exercises with each positional change can help, and some hospital beds have the capability of placing the patient into a chair-like seated position that can also be beneficial. The development of pressure sores should not occur with good nursing care practices, and their occurrence can significantly impact upon hospital length of stay, health economics, patient comfort and stroke morbidity (112). Vigilant mouth care can prevent complications such as oral candida colonization and the development of candida pneumonia in aspirating patients, a serious complication that will significantly impact length of stay and patient mortality and morbidity rates (112).

The prevention of VTE is complicated, as the use of anticoagulants carries the best evidence, but use in the initial period may cause haemorrhagic expansion in a patient with an IPH (112). To date, there are no large trials that have fully vetted the safety of anticoagulation use in haemorrhagic stroke, but most experts agree that once the haemorrhage has stabilized, use of anticoagulation is probably safe; therefore, most Stroke Centres start anticoagulation after 36-48 hours (30). In ischaemic stroke, anticoagulation for VTE prophylaxis is considered standard of care, and has not been shown to increase the risk of significant haemorrhagic transformation (35, 112, 113). Research has found the use of graduated compression stockings to be ineffective at preventing VTE in patients suffering from stroke, and there is concern that below-knee stockings may increase VTE risk, and if improperly sized cause limb ischaemia (113). Sequential compression devices have been shown to reduce VTE risk, but may cause skin breakdown if improperly applied and managed, so good nursing care is important to successful, safe use (35, 113).

The routine use of indwelling catheters to manage urinary incontinence post stroke is not encouraged and bladder training as part of continence programs should begin early in hospitalization (43). In the event that a patient develops urinary retention, a temporary “in-out” catheter should be used, where the catheter is inserted long enough to empty the bladder and then removed (52). Because catheter insertion is an invasive procedure, it should be avoided within the first 24 hours following alteplase administration due to increased bleeding risk. A catheter may be required in patients needing close monitoring of their fluid balance status, such as patients with congestive cardiac or renal failure, or those requiring significant fluid resuscitation (43).

Smoking is a major risk factor for stroke and all patients who smoke should be counseled about smoking associated risks, and the benefits of quitting during their acute stay (35, 52). This can be reinforced along the recovery journey, especially if they are transitioned to a rehabilitation facility. To increase the likelihood that the patient will quit permanently, the patient’s family and significant others should be involved in counseling sessions, so that they may act as support in times of need. While the patient is in hospital, nicotine replacement products should be offered as part of a smoking cessation plan (43).

Nurses play a vital role in providing stroke education to the patient and their family. In the initial phases of hospitalization, the patient and their family may not retain much information, requiring it to be repeated more than once. Topics that will need to be covered include:

- The stroke process (ischaemic and/or haemorrhagic)
- Stroke symptoms and warning signs
- Stroke treatments
- Prevention of complications
- Hospital discharge planning
- Stroke recovery, including the rehabilitation process
- Personal risk factors and modification strategies
- When and how to call for an ambulance (35, 43, 52).

Patients with an ischaemic stroke may require additional management strategies to improve their outcomes and reduce their future stroke risks. In the event of a large MCA or cerebellar stroke, malignant cerebral oedema can develop which may significantly increase ICP, causing tissue

compression, herniation, coma and subsequently death. As the brain atrophies with age creating space within the cranial vault, older patients with significant atrophy at baseline are at lower risk for development of malignant oedema, however, in young patients even small amounts of oedema can be life threatening. Craniectomy procedures remove a large section of the skull and prevent brain compression, allowing the infarcted brain to swell outside the boundaries of the skull (114, 115). Craniectomy is considered a lifesaving procedure, but does not reduce disability levels (114). The removed skull segment is stored in a bone bank or sewn into a pouch that is created inside the abdomen, and the patient is placed on helmet precautions. Approximately 3 months after stroke, the bone segment is replaced. In craniectomy for cerebellar stroke, the skull segment is not replaced post-operatively (43).

In ischaemic stroke, prophylactic secondary prevention is generally a triple therapy of an antiplatelet, (or anticoagulant in the setting of AF), antihypertensive agents, and a statin (35, 116). Options for antiplatelet agents include aspirin, clopidogrel or aspirin-extended release dipyridamole (116-118). When prescribing an antiplatelet agent, clinicians should consider whether the patient is anti-platelet "naive" or if there has been an antiplatelet failure, that is, the stroke occurred while the patient was already on an antiplatelet. Other considerations include if the patient has a history of migraines, cardiac disease or a cardiac stent. Concomitant medications, including drugs like COX-2 selective non-steroidal anti-inflammatories and protein pump inhibitors should also be taken into account, due to potential interactions or risk of gastrointestinal bleeding (43). The use of dual antiplatelet agents (aspirin and clopridogrel) has been shown to reduce major ischaemic events, including subsequent stroke and myocardial infarction, at 90-days post stroke, but at the risk of increased bleeding and therefore should be considered on an individual-patient basis (119). It is well established that anticoagulation is beneficial for stroke prevention in patients with AF (120, 121). In an attempt to objectively gauge the risk of stroke, scores such as the $CHADS_2$ or CHA_2DS_2-VASc may be used (122, 123). Until recently, warfarin was the only long-term oral anticoagulant available for use, but with the recent release of direct oral anticoagulants (DOACs) onto the market, patients now have more options. Benefits of DOACs are a static dose regime that may improve patient compliance, and no need for regular blood testing. Currently, only one DOAC agent, Dabigatran, has a direct reversal agent available and due to their half-lives, DOACs are generally considered an exclusion criteria for thrombolytic therapy if taken within 12-24 hours of stroke onset, unless clotting tests can show sub-therapeutic levels. Each DOAC has a different safety profile which needs to be carefully considered before prescribing (124-126). Both ischaemic and haemorrhagic stroke patients benefit from BP control. Over the course of a hospital admission BP should be progressively lowered generally using at least two, if not more, antihypertensive agents. Patients should be followed-up after discharge to ensure they achieve their BP control targets (7). Aggressive early blood pressure reduction is not recommended and may place patients at risk for deterioration (17). Regardless of cholesterol levels, high dose statins have been found to reduce the risk of stroke, TIA and cardiovascular events (104, 127-129).

Patients who present with a SAH commonly develop vasospasm, which can restrict arterial flow to the point of causing a secondary ischaemic stroke. Treatment has traditionally included use of "triple H" therapy (HT, hypervolaemia and haemodilution), however very little evidence supports hypervolaemia and haemodilution, and only small studies have shown HT to be efficacious (130). Other vasospasm treatments include IA angioplasty and IA calcium channel blocker administration with verapamil or nicardipine, although 3 month outcome data showing efficacy are lacking to support these practices (131). An external ventricular drain (EVD) may be inserted for CSF diversion and intracranial monitoring in patients with high Hunt and Hess grade aSAH. EVD CSF drainage should be carefully monitored. It is imperative that the EVD system be maintained as a closed sterile system to prevent infection and minimize development of ventriculitis. Once CSF drainage has become stable, the system can be clamped and the patient monitored for increased ICP; when ICP is

found to be stable, the patient can have the EVD removed. However, at times some patients with EVD need to progress to long-term shunt placement. Nimodipine is considered standard of care to increase brain tissue thresholds/tolerance of ischaemia developing from vasospasm, but the drug does nothing to reduce vasospasm itself. Following aSAH, myocardial stunning can occur, but is often time limited and fully reversible; however, when it occurs, it can significantly challenge the ability to perfuse through spastic arterial segments due to concurrent vasospasm (132). Use of inotropic therapies while paying close attention to myocardial oxygen demand/consumption can enhance heart function, but requires cautious management to prevent heart failure (43).

Case Study 2 Part B: John returns from the endovascular suite having undergone coiling of a ruptured aneurysm. He has a puncture wound in the right groin where femoral arterial access was obtained. He is intubated, ventilated and is slowly regaining consciousness. A EVD with ICP monitoring is in place as well as a central line and peripheral IV. His vital signs are BP 140/70, HR 80, T 38.2, ICP = 12 mmHg.

1. *Develop a care plan for John's initial first day in ICU coil embolization.*
2. *Describe when John's risk for vasospasm will be maximal, and how he will be monitored for this complication.*
3. *What advice and information will you provide to John's wife on admission to ICU?*

Case Study 1 Part C: Julie has received an emergency endovascular clot removal.

1. *Develop a care plan for Julie to ensure an event-free recovery.*
2. *What education and advice will you provide to Julie and her daughter on discharge?*

CONCLUSION

In summary, stroke is a global medical emergency and prompt recognition and aggressive treatment at specialist stroke centres is essential to reducing neurological disability and mortality rates. In the case of ischaemic stroke, practitioners must adopt a philosophy of "finding reasons to treat" with intravenous alteplase whenever possible, because it remains the only widely available medicinal therapy proven to reduce disability at no increased risk of death. Intra-arterial therapies are now shown to improve 3-month outcome in large artery ischemic stroke, but this technology is not available at most centres throughout the world, making alteplase treatment even more important. Unfortunately, haemorrhagic stroke remains a troubling disease with few treatment options, carrying high rates of disability and death. The ED, neuroimaging departments, and stroke team play a vital role in hyperacute stroke care, as earlier treatment significantly improves patient outcome and the likelihood of returning to premorbid levels of functioning. Once in the stroke unit, the nursing, medical and multidisciplinary teams are the first line of defense against neurological deterioration and stroke associated complications. Stroke care in the 21st century is truly a team effort and the future is primed for more innovative stroke research, including world class nursing research to further reduce the burden of this crippling disease.

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