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SUDAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

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Assessment of the Ischemic Acute Stroke Using Magnetic Resonance Diffusion Weighted Imaging

تقييم الجلطة الدماغية الحادة باستخدام التصوير بالرنين المغنطيسي الموزون على الإنتشار

A proposal submitted in fulfillment of the requirement for the degree of M.Sc in Diagnostic Imaging Technology

By

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

قال تعالى:

﴿ أَمَّنْ هُوَ قَانِتٌ آنَاءَ اللَّيْلِ سَاجِدًا وَقَائِمًا يَحْذَرُ الْآخِرَةَ وَيَرْجُو رَحْمَةَ رَبِّهِ قُلْ هَلْ يَسْتَوِي الَّذِينَ يَعْلَمُونَ وَالَّذِينَ لَا يَعْلَمُونَ إِنَّمَا يَتَذَكَّرُ أُولُو الْأَلْبَابِ ﴾

[الزمر: 9]

Dedication

I dedicate this project to ALLAH the Almighty, my creator and source of strength. I also dedicate this work to my family and my precious friends.

A special gratitude to my loving parents: Hafzalla and Suaad whose words of encouragement and push for tenacity ring in my ears.

I also dedicate this dissertation to my friends who have supported me throughout the process. I will always appreciate all they have done, especially

My senior radiotechnologist Medhat for helping me develop my technology skills, the many hours of proofreading, and for helping me to master the leader dots. I dedicate this work and give special thanks to my two best friends Esraa and Mawada and my wonderful sister Arwa for being there for me throughout the entire master's program.

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Abstract

Diffusion-weighted MRI (DWI) is highly sensitive in detecting early cerebral ischemic changes in acute stroke patients. This study aimed to show the role of diffusion-weighted MRI (DWI) in the diagnosis of acute stroke. In this study, we compared the role of DWI with that of conventional MRI techniques. Furthermore, we compared the size of ischemic lesions on DWI scans with the fluid-attenuated inversion recovery (FLAIR) images. We performed T1-weighted imaging (T1WI), T2-weighted imaging (T2WI), FLAIR, and DWI MRI in 30 patients who presented with acute stroke. The size of ischemic lesions was measured on DWI and FLAIR images.

With DWI, 100% of the ischemic lesions were detected, with FLAIR recovery 83% were detected, whereas with T1-weighted and T2-weighted images, only 63% of lesions were identified. The size of the lesion on DWI scans was larger than the FLAIR images.

DWI is more sensitive than conventional MRI in detecting early ischemic lesions in acute stroke patients. The size of the lesions measured on DWI and FLAIR images in the first 6 h was larger than those measured between 6 h and 3 days. MRI is recommended strongly for the accurate diagnosis of acute stroke.

ملخص الأطروحه

التصوير بالرنين المغنطيسي الموزون بالإنتشار هو تقنية لها حساسية عالية للكشف المبكر عن التغيرات المتعلقة بنقص التروية الدماغية لمرضى السكتة الدماغية الحادة. هذه الدراسة تهدف لعرض درو التصوير بالرنين المغنطيسي الموزون بالإنتشار في تشخيص السكتة الدماغية. في هذه الدراسة تمت مقارنة التشخيص بالتصوير بالرنين المغنطيسي الموزون بالإنتشار مع التشخيص بالتقنيات التقليدية الاخرى للتصوير بالرنين المغنطيسي. علاوة على ذلك, تمت مقارنة احجام المناطق المتضررة بنقص التروية الظاهرة على صور التصوير الموزون بالإنتشار مع مثيلاتها في صور إسترداد انقلاب السوائل الموهّن.

تم عمل التصوير الموزون T1, والتصوير الموزون T2, وصور استرداد انقلاب السوائل الموهّن, والتصوير الموزون بالانتشار ل30 مريض قدموا بسكتة دماغية حادة. وتم قياس احجام المناطق المتضررة بنقص التروية الدماغي فقط على صور إسترداد انقلاب السوائل الموهّن و التصوير الموزون بالانتشار.

في التصوير الموزون بالإنتشار, تم إكتشاف 100% من المناطق المتأثرة بنقص التروية للمرضى, و في صور إسترداد انقلاب السوائل الموهّن تم إكتشاف 83%, بينما في لتصوير الموزون T1 و التصوير الموزون T2, تم إكتشاف 63% فقط من هذه المناطق. حجم هذه المناطق المتضررة في صور الرنين المغنطيسي الموزون بالإنتشار كان اكبر من مثيلاتها في صور إسترداد انقلاب السوائل الموهّن.

التصوير بالرنين المغنطيسي الموزون بالإنتشار لديه حساسية أعلى من تقنيات التصوير بالرنين المغنطيسي التقليدية الأخرى في الكشف عن آفات نقص التروية الدماغية المبكرة لدى مرضى السكتة الدماغية الحادة.

ينصح بالتصوير بالرنين المغنطيسي بشدة للتشخيص الدقيق لمرض السكتة الدماغية الحادة.

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TABLE OF CONTENTS

No.	Subjects	Page No.
	الآية	I
	Dedication	II
	Acknowledgement	III
	Abstract, English	IV
	Abstract, Arabic	V
	Table of contents	VI
	List of tables	VIII
	List of figures	IX
	Abbreviations	X
CHAPTER ONE: INTRODUCTION		1
1.1	Introduction	2
1.2	Problem of the Study	4
1.3	Aim of the study	4
CHAPTER TOW: Literature Review		5
2	Literature Review	6
2.1	Definition	6

No.	Subjects	Page No.
2.2	Anatomy and divisions of the Cerebrovascular Circulation	7
2.2.1	The Arterial System	10
2.2.2	The Venous System	19
2.3	Classification of stroke	19
2.4	Pathophysiology	22
2.5	Complications of acute stroke	23
2.6	Diagnosis and investigation of acute stroke	23
2.6.1	Radiographic diagnosis	24
2.7	Magnetic Resonance Imaging in Stroke	25
2.7.1	Diffusion-weighted imaging (DWI)	25
2.8	Diffusion-weighted imaging (DWI) for the assessment of acute stroke	26
2.9	Previous studies	26
CHAPTER THREE : MATERIALS AND METHODS		28
3.1	Materials	29
3.1.1	Study design	29
3.1.2	Study area	29
3.1.3	Study duration	29
3.1.4	Study population	29

No.	Subjects	Page No.
3.1.5	Sample size	29
3.2	Methodology	30
3.2.1	Preparation of patients	30
3.2.2	Imaging protocol	30
3.2.4	Technique	30
CHAPTER THREE : RESULTS		31
4.1	Demographic and clinical data of all study population	32
CHAPTER FIVE : DISCUSSIN AND CONCLUSION		37
5.1	Discussion	38
5.2	Conclusion	39
5.3	Recommendations	40
5.4	References	41
5.5	Appendices	43

List of Tables

Table No	Title	Page
2.1	The sizes of brain infarcts on T1WI, T2WI, FLAIR and DWI of the sample	16
2.2	Time of sequences used on MR imaging	17
3.1	Mean size (length × width) of the infarctions detected as seen on FLAIR and DWI	42
3.2		44
4.1		47

List of Figures

Figure No	Title	Page
2.1	Anterior circulation	10
2.2	Posterior circulation	10
2.3	Circle of Willis	12
2.4	Case study 1	31
2.5	Case study 2	32
2.6	Case study 3	33
2.7	Case study 4	35
2.8	Case study 5	36
2.9	Case study 6	37
2.10	Case study 7	39
2.11	Case study 8	40
4.1	Case study 9	46
5.1	Chart showing the incidence rate of acute stroke in the study sample	48
5.2	Chart showing the age ranges of the study sample	49
5.3	Case study 10	50
5.4	Case study 11	51
5.5	Case study 12	52

List of Abbreviation

ACA: Anterior cerebral artery
AChA : Anterior choroidal artery
AICA: Anterior inferior cerebellar arteries
ACoA: Anterior communicating artery
BBB : Blood Brain Barrier
C1: First cervical vertebra
C7: Seventh cervical vertebra
CNS: Central Nervous System
CT: Computed Tomography
CVA Cerebrovascular Accident
DWI: Diffusion Weighted Imaging
EPI: Echo planar imaging
FLAIR: Fluid Attenuated Inversion Recovery
ICA: Internal carotid artery
IR: Inversion recovery
MCA: Middle cerebral artery
MRI: Magnetic Resonance Imaging
PCA: Posterior cerebral artery
PCoA: Posterior communicating artery
PICA: Posterior inferior cerebellar artery
RF: Radiofrequency
SCA: Superior cerebellar arteries
SE: Spin echo
T1W: T1 Weighted Imaging
T2W: T2 Weighted Imaging
TE: Time to echo
TIA: Transient ischemic accident
TR: Time to repeat

Chapter One

Introduction

Chapter One

1.1 Introduction

Stroke or cerebrovascular accident (CVA) is defined as the sudden occurrence of a focal, non-conclusive neurologic deficit; with variable sequences, ranging from subtle to very severe disabilities, depending on the area of the brain involved and the nature of the attack. Stroke is caused by the interruption of the blood supply to the brain, usually because a blood vessel bursts or is blocked by a clot. This cuts off the supply of oxygen and nutrients, causing damage to the brain tissue. (Ibrahim, E.A.A. and Ahmed, M.A.M., 2019) Stroke is the second leading cause of death worldwide and in the European region. Ten percent of the 55 million deaths that occur every year worldwide are due to stroke (Sebate E and Wimalaratna S, *et al.*,2004).

In the western world, stroke is the third commonest cause of death (after heart disease and all cancers), considered the commonest cause of severe disability, and accounts for a large proportion of healthcare resources. Its impact on individual patients, their families, and society as a whole is immense. About 200 people per 100,000 population will have a first ever stroke every year. Their mean age is about 72 years, and men and women are affected in roughly equal numbers. Despite the uncertainty over whether stroke incidence is rising, falling, or remaining static, the absolute number of patients is likely to increase, as its incidence increases with age and most populations are aging. Therefore, Stroke is the commonest life-threatening neurological disorder, and the resulting disability is the most important single cause of severe disability among different populations. An acute stroke refers to the first 24-hour- period of a stroke, which is a very critical period that requires immediate diagnosis because some patients may require instant treatment. There are several reasons why many patients require urgent inpatient care after an acute stroke. Firstly, stroke may lead to various potentially life threatening complications such as airway obstruction and respiratory failure,

swallowing problems with the risk of aspiration, dehydration and malnutrition, venous thromboembolic complications, seizures, and infections. These may arise within hours of stroke onset and require early assessment and intervention so that they can be anticipated, prevented, and treated. (Davenport R and Dennis M, 2000)

Diagnosis of acute stroke typically based on a physical exam and supported by medical imaging such as a CT scan or MRI scan. A CT scan can rule out bleeding, but may not necessarily rule out ischemia, which early on typically does not show up on a CT scan. Other tests such as an electrocardiogram (ECG) and blood tests are done to determine risk factors and rule out other possible causes. Low blood sugar may cause similar symptoms. (Mozaffarian D *et al.*, 2015) Magnetic resonance imaging is probably more sensitive than CT for detecting stroke, particularly lacunar strokes and those occurring in the posterior fossa. However, even MRI can be normal in clinically definite stroke.31 Certain MRI techniques, such as diffusion weighted imaging, are very sensitive at highlighting the "culprit" lesion, which may be useful when several areas of abnormality are shown. The differentiation between an ischaemic and haemorrhagic stroke on MRI in the first few days is less easy for the non-expert than with CT but MRI can help diagnose intracerebral haemorrhage months or even years after the event when CT shows only a hypodense area indistiguishable from an infarct. Therefore, MRI, including the use of specific sequences such as diffusion weighted imaging, may add significantly to the understanding of stroke mechanisms (Davenport R and Dennis M, 2000). Diffusion-weighted MRI (DWI) provides potentially unique information on the viability of brain tissue. It provides image contrast that is dependent on the molecular motion of water, which may be altered markedly by disease. The method was introduced into clinical practice in the mid-1990s. The primary application of DWI has been in brain imaging, mainly because of its high sensitivity to ischemic stroke — a common condition that appears in the differential diagnosis in almost all patients who present with a neurologic complaint. (Baird, A.E. and Warach, S., 1998)

1.2 Problem of the Study:

MRI is the modality of choice regarding the diagnosis of acute stroke as it has the ability to detect the cerebral changes in the first 24 Hours of stroke onset, unlike other modalities or other MRI sequences.

DWI is highly sensitive in detecting early cerebral ischemic changes in acute stroke patients in relation to other conventional MRI techniques.

Furthermore, the size of ischemic lesions on DWI scans is more accurately assessed in compare with the fluid-attenuated inversion recovery (FLAIR) images.

1.3 Aim of the study

1.3.1 General objective.

- This study aims to evaluate the diffusion-weighted MRI (DWI) technique in the diagnosis of acute stroke.

1.3.2 Specific objectives

- To define the role of DWI in detecting early cerebral changes in acute stroke patients.
- To compare the sensitivity of DWI in identifying stroke lesions in relation to other conventional MRI techniques/sequences.
- To compare the size of the lesions on DWI scans with the fluid-attenuated inversion recovery (FLAIR) images.

Chapter Two

Literature review

Chapter Two

2 Literature review

2.1 Definitions of stroke:

Stroke, is an abrupt onset of a focal neurological deficit lasting more than 24 hours. It is also called cerebrovascular accident (CVA) or apoplexy. (Sabaté, E. and Wimalaratna, S., 2004) An **acute stroke** is a the term used to describe the first 24-hours period of a stroke. (Sacco RL *et al.*,2013)

The term "stroke" should be broadly used to include all of the following:

Definition of ischemic stroke: An episode of neurological dysfunction caused by focal cerebral, spinal, or retinal infarction. (Note: Evidence of CNS infarction is defined above.) (Sacco RL *et al.*,2013)

Definition of intracerebral hemorrhage: A focal collection of blood within the brain parenchyma or ventricular system that is not caused by trauma. (Sacco RL *et al.*,2013)

Definition of stroke caused by intracerebral hemorrhage: Rapidly developing clinical signs of neurological dysfunction attributable to a focal collection of blood within the brain parenchyma or ventricular system that is not caused by trauma. (Sacco RL *et al.*,2013)

Definition of silent cerebral hemorrhage: A focal collection of chronic blood products within the brain parenchyma, subarachnoid space, or ventricular system on neuroimaging or neuropathological examination that is not caused by trauma and without a history of acute neurological dysfunction attributable to the lesion. (Sacco RL *et al.*,2013)

Definition of subarachnoid hemorrhage: Bleeding into the subarachnoid space (the space between the arachnoid membrane and the pia mater of the brain or spinal cord).

Definition of stroke caused by subarachnoid hemorrhage: Rapidly developing signs of neurological dysfunction and/or headache because of bleeding into the subarachnoid space (the space between the arachnoid membrane and the pia mater of the brain or spinal cord), which is not caused by trauma. (Sacco RL *et al.*,2013)

Definition of stroke caused by cerebral venous thrombosis: Infarction or hemorrhage in the brain, spinal cord, or retina because of thrombosis of a cerebral venous structure.

Symptoms or signs caused by reversible edema without infarction or hemorrhage do not qualify as stroke. (Sacco RL *et al.*,2013)

Definition of stroke, not otherwise specified: An episode of acute neurological dysfunction presumed to be caused by ischemia or hemorrhage, persisting ≥24 hours or until death, but without sufficient evidence to be classified as one of the above. (Sacco RL *et al.*,2013)

2.2 Anatomy and divisions of the Cerebrovascular Circulation:

The cerebrovascular circulation is considered the most important because arrest of the circulation for 5 minutes can lead to brain death. Just like the circulation to the rest of the body, the cerebral circulation originates in the left heart and is conducted by the aorta. The conduction of blood begins during systole, with the left ventricular ejection of oxygenated blood into the aorta. As the aorta ascends, it becomes the ascending aorta and subsequently forms the aortic arch, which gives rise to three branches. The first and largest branch is the brachiocephalic trunk, which originates behind the manubrium; the second branch is the left common carotid artery, which originates to the left of the brachiocephalic trunk; and the third is the left subclavian artery, which ascends with the left common carotid artery through the superior mediastinum and along the left side of the trachea. The vertebral arteries arise as the most proximal ascending branch from the subclavian arteries on each side of the body and enter deep into the cervical vertebra transverse processes, typically at the level of the 6th cervical vertebra, but about 7.5% of the time at the level of C7. Other variations in the vertebral arterial route have also been noted, including anomalies in intraforaminal position. The arteries proceed superiorly in the transverse foramen of each cervical vertebra, until they pass through the transverse foramen of the atlas (C1). Once here, they make a sharp posterior bend, traveling across the posterior arch of C1 and through the suboccipital triangle, piercing the dura mater on their way toward the foramen magnum, which marks the beginning of the intracranial course. The vertebral arteries are known to be bilaterally symmetrical in course, but a marked lateral variation in the origin of the common carotid arteries is a characteristic of

human anatomy. While the left common carotid artery arises directly from the aortic arch, the right internal carotid artery (ICA) arises from the brachiocephalic trunk. (Chandra, A *et al.,* 2017)

The first and largest branch of the arch, the brachiocephalic trunk, originates on the right side of the chest near the trachea, and bifurcates posterior to the sternoclavicular joint into the right subclavian artery and right common carotid artery as it moves rightward within the superior mediastinum. On the left side of the body, however, there is no brachiocephalic trunk: on this side, the common carotid artery comes directly from the aortic arch as its second branch. Despite this variation in origin, the common carotid arteries then pursue a symmetrical ascent in the chest, ending as they split into the internal and external carotid arteries at the superior border of the thyroid cartilage, at around the level of fourth cervical vertebra. Unlike the external carotid arteries, the internal carotid arteries do not give off any branches in the neck. The only task of these vessels is to supply the brain's anterior circulatory system, which they begin to do after entering the cranial cavity just anteriorly to the jugular foramen, through the carotid canal. To begin with its simplest anatomical classificatory scheme, the cerebral circulation is composed of a supplying arterial circulation and a draining venous circulation. The arterial system can then itself be subdivided according to anatomical position, into anterior and posterior cerebral circulations, as has been discussed. One can also divide the arterial circulation by size. According to this scheme, the macrocirculation may be considered to comprise the gross branches of the cerebral vascular responsible for the regional perfusion of the cerebrum. The microcirculation is then derivatively defined as the microscopic site of oxygen and nutrient exchange within the vasculature, as well as of the blood–brain barrier (BBB). Continuing with the anatomical scheme, the microcirculation is terminally productive of the brain's venous circulation: a freely communicating, interconnected system of dural venous sinuses and cerebral veins. (Chandra, A *et al.*, 2017)

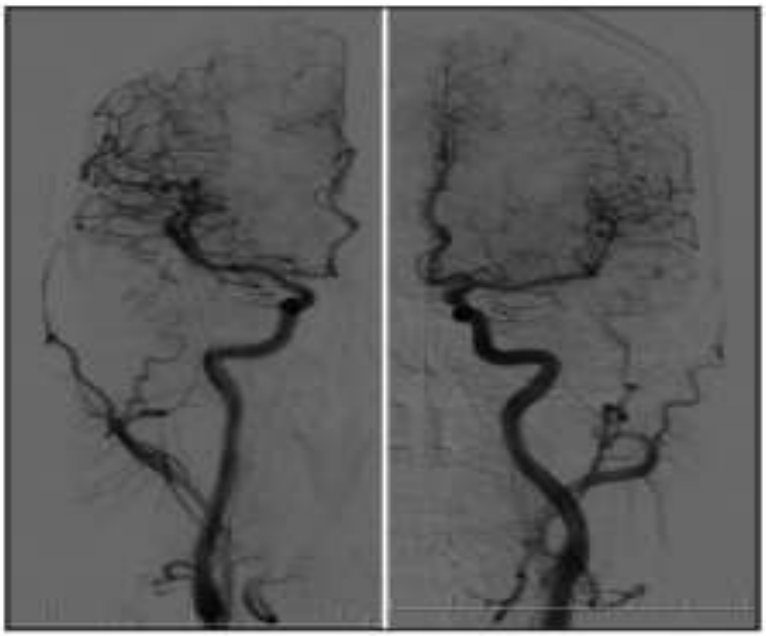

Figure (2.1): Anterior circulation: Left and right internal carotid arteries as seen with angiography (Chandra, A *et al.*, 2017)

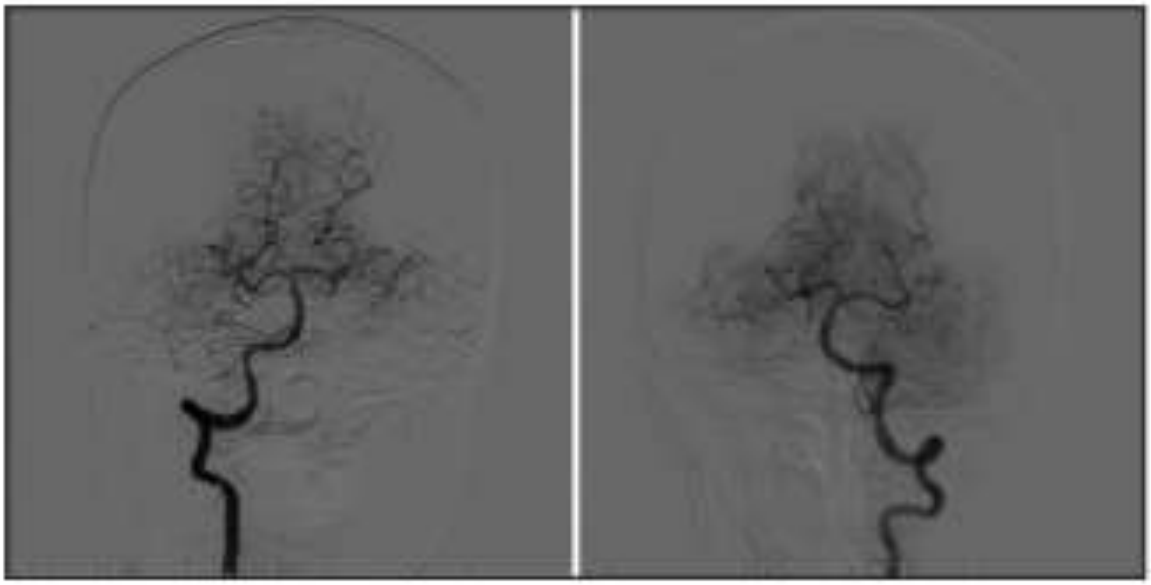

Figure (2.2): Posterior circulation: Left and right vertebrobasilar artery system as seen with angiography (Chandra, A *et al.*, 2017)

2.2.1. The Arterial System

Following their entry into the cranial cavity, the internal carotid and vertebral arteries fulfill the formidable role of exclusive suppliers of the blood necessary to maintain the brain, and all its many crucial functions, in working order (note that this is not the only function served by these enormously important vessels; the arterial networks also drain interstitial fluid and protein from the brain). It has already been mentioned that the carotids are the major conduit for blood, but the vertebral supply should not therefore be discounted. Before and after anastomosing to form the single, midline basilar artery, the vertebral vessels represent the primary supply of blood to the brainstem; compromise of this system can thus entail catastrophic consequences related to disruption in the critical brainstem autonomic centers. (Chandra, A *et al.*, 2017)

By contrast, both circulatory divisions provide major branches to the diencephalic and telencephalic regions of the brain proper. To do so, the circulations first meet as the Circle of Willis [Figure 2.3]: an arterial wreath, located approximately within the brain's interpeduncular fossa, and surrounding the optic chiasm. Initially described by Thomas Willis in 1664, the circle is a salient anatomical landmark of considerable anatomic variability. Variability notwithstanding, it is in any case the critical anastomotic junction between the internal carotid and vertebral artery supply to the brain, from which the rest of the major branches stem. It therefore occupies a very important position in the collateral pathway of cerebral arteries. This becomes especially important in ischemic conditions, under which variation can predispose patients to pathology. For example, a study of 976 atherosclerotic patients found that an incomplete anterior Circle of Willis, present in 23% of the study population, carries a hazard ratio of 2.8 for future anterior circulation ischemic strokes. In addition, it has been proposed that demographic variation in this arterial wreath may partially explain the different incidence of some varieties of cerebrovascular diseases in different racial groups. (Chandra, A *et al.*, 2017)

The branches of the circle are as follows: the anterior cerebral artery (ACA), anterior communicating artery (ACoA), ICA, posterior cerebral artery (PCA), posterior communicating artery (PCoA), and basilar artery. From their origin within the interpeduncular fossa, these branches course centrifugally toward their divergent cerebral targets, becoming the cerebral arteries that are grossly visible covering the cortical surface (also known as leptomeningeal arteries), or ending as perforating or choroidal branches to deeper structures. We will not treat these tiny and numerous terminal branches in any detail, but, since it is indispensable to a working appreciation of normal neurovascular function, we will discuss each of the larger branches in detail. Moreover, an understanding of the course of (and structures supplied by) these vessels is also the foundation necessary to localize and treat stroke, which will be the subject of our follow-up paper. (Chandra, A *et al.*, 2017)

Figure (2.3): Circle of Willis as seen with magnetic resonance angiography (Chandra, A *et al.*, 2017)

2.2.1.1. The Anterior Cerebral Circulation

The anterior cerebral circulation is composed of branches from the ICA. There are many such branches, but the ACA, middle cerebral artery (MCA), and the anterior choroidal artery (AChA) are highly prominent and pathophysiologically significant. Overall, the function of the anterior division of the cerebral circulation is to supply blood to a large proportion of the forebrain, including the frontal, temporal, and parietal lobes, as well as parts of the diencephalon and internal capsule. The contribution of the anterior circulation to total cerebral blood flow has been measured by phase-contrast magnetic resonance imaging (MRI) at 72%. (Chandra, A *et al.*, 2017)

2.2.1.1.1. Anterior cerebral artery

The ACA primarily supplies blood to the most medial aspect of the cerebral cortical surface, located along the longitudinal fissure that divides the brain's two hemispheres. This area includes portions of the frontal lobes, as well as the superomedial parietal lobes; because it ends rostral to the parieto-occipital sulcus, this artery does not supply the medial occipital lobe. Its course is as follows: after arising from the anterior clinoid portion of the ICA, it courses anteromedially over the superior surface of the optic chiasm, toward the longitudinal fissure. Shortly after arrival in the fissure, it forms an anastomosis with the contralateral ACA. This anastomosis is called the anterior communicating artery. While small, this artery is nevertheless the most common location of (36%) of cerebral aneurysms and is thus of enormous pathological importance. It also marks the first segmental division of the ACA, which is divided regionally into five segments along its course: A1–A5. Table (2.1) describes these segments, their major branches, the structures they supply, and the significance of any anatomical variation associated with them. As the ACA proceeds, then, beyond A1, it begins its posterior course toward the parieto-occipital sulcus, following the contour of the callosal sulcus between the two cerebral hemispheres. Throughout this whole course,

the ACA provides deep and cortical branches; these arise from the proximal and distal portions of ACA, respectively. (Chandra, A *et al.*, 2017)

2.2.1.1.2. Anterior choroidal artery

AChA is a branch of the ICA that typically arises from the supraclinoid portion, just before the bifurcation of the middle and anterior cerebral arteries. However, many anatomical variations have been found: AChA has also been found to originate from the MCA or even from the PCoA. Although rare, still other variations have also been observed, including complete absence, as well as duplication, of AChA. As should hardly be surprising given this variety of possible courses, the vascular territory of the AChA has been a matter of debate in recent years. Whatever its course, However, the AChA gives off both deep and superficial branches. The vascular territory of the deep branches includes the posterior two-thirds of the internal capsule, adjacent optic and auditory radiations, medial portion of the globus pallidus, and tail of the caudate nucleus; the territory of the superficial branches includes piriform cortex and uncus, hippocampal head, amygdala, and most lateral portion of the thalamic lateral geniculate nucleus. (Chandra, A *et al.*, 2017)

2.2.1.2. Middle cerebral artery

MCA is the largest and most complexly distributed of the cerebral vessels, supplying many critical cerebral structures along its sinuous course. Neither that the MCA is the most common site of stroke, nor that large-territory MCA strokes often carry a very poor prognosis, should therefore come as a surprise. The artery has a relatively consistent route: variations have been found in 3.8% of patients, and have not been determined to be of clinical significance. It originates from the bifurcation of the ICA, just lateral to the optic chiasm at the medial end of the Sylvian fissure, and passes laterally from there along the ventral surface of the frontal lobe, entering the Sylvian fissure between the

temporal lobe and insular cortex. Within this region, the artery typically bifurcates or trifurcates, giving rise to two or three principal trunks. These, in turn, extend superiorly and inferiorly over the insular surface, supplying, by means of an arterial arborization that ultimately extends over most of the lateral surface of the cerebral hemisphere, the following cortical territories: all of the insular cortex and opercular surface, the superior and middle temporal gyri, a parietal territory that comprehends the inferior parietal lobule and much of the postcentral gyrus, and a frontal territory that comprehends inferior and middle frontal gyri, much of the precentral gyrus, and the lateral part of the orbital surface. Just as has been seen above for the sake of rendering a large and sinuous vascular route more comprehensible in the case of the ACA, these many MCA territories have been partitioned into segments. (Chandra, A *et al.*, 2017)

2.2.1.3. The Posterior Cerebral Circulation

Although it provides only about one-third of the total flow perfusing the brain, the posterior cerebral circulation still maintains many of the nervous system's most critical functions. Also known as the vertebrobasilar circulation, it is comprised of the vertebral arteries, the basilar artery into which the vertebrals fuse, and several branches from these main conduits to be detailed below. This circulation may be broadly considered to supply blood to the posterior portion of the brain that includes the occipital lobe, most of the anterior and posterior portions of the brainstem, and all of the cerebellum. Beginning with its origin in the vertebral arteries, we will now provide an anatomically organized overview of this circulatory division, because it is a less frequent focus of cerebrovascular pathology, accounting for only 20% of ischemic strokes. (Chandra, A *et al.*, 2017)

2.2.1.4. Vertebral arteries

As introduced above, these are paired, bilaterally symmetrical arteries that arise from the subclavian vessels on each side of the body. Like the MCA, they have been partitioned, for the sake of organizational clarity, into four segments. Unlike MCA, the first three of these segments are extracranial. The most proximal segment, V1, extends from the vessels' subclavian origin to the vertebral transverse foramen, and is, along with the distal V4, the most common site of vertebral artery infarction. The succeeding V2 segment then courses through the transverse foramen. V3, which has already been discussed for the predisposition to hemorrhage possessed by its shortened variations, loops from approximately the level of C2 around the atlas and then enters the dura. Once through the dura, the arteries become V4 – this is the intracranial segment of the vertebral arteries. Running from its dural entrance to the rostral medulla or caudal pons, this segment has many vascular tasks. Immediately after entering the brain through the foramen magnum and prior to its anastomosis at the caudal pontine level, it gives rise to two important branches. The first of these is the posterior inferior cerebellar artery (PICA). Second, and immediately proximal to the anastomosis, each V4 gives rise to a small branch that joins its contralateral counterpart to form the descending, midline anterior spinal artery. There is also a set of posterior spinal arteries. These may arise either from PICA or from the vertebral arteries, but will not be discussed further, due to the relatively small brainstem territory they supply, as well as the rarity and variability characteristic of lesions in these vessels. (Chandra, A *et al.*, 2017)

2.2.1.4.1. Posterior inferior cerebellar artery

PICA is the largest branch of the vertebral artery. After splitting off from its vertebral origin, it winds posteriorly around the upper medulla, passes between the origins of the vagus and accessory nerves, and then proceeds along the inferior cerebellar peduncle to reach the ventral surface of the cerebellum, where it divides into medial and lateral

branches. The artery provides blood to the part of the medulla and cerebellum corresponding to its course: the dorsolateral region of the medulla and a region of the ventral surface of the cerebellar hemispheres that includes the inferior vermis. PICA lesions produce the symptoms consistent with this distribution, including ipsilateral loss of facial pain and temperature sensation, contralateral loss of the same in the body, cerebellar ataxia, and bulbar palsy. This collection of symptoms composes the classical neurological syndrome known as Wallenberg's syndrome. (Chandra, A *et al.*, 2017)

2.2.1.4.2. Anterior spinal artery

As already discussed, the anterior spinal artery arises as a midline anastomosis of two small branches from the vertebral arteries. From this anastomosis, the artery proceeds within the anterior median fissure down the whole length of the spinal cord. Before doing so, however, it rests on and supplies a region in the anterior medulla. Consequently, like PICA, anterior spinal artery lesions are associated with a characteristic neurological syndrome, with symptoms consistent with hypoperfusion of the medullary regions normally supplied by this vessel. (Chandra, A *et al.*, 2017)

2.2.1.5. Basilar artery

After its anastomosis at the pontomedullary junction, the paired V4 segments give way to a single, massive basilar artery that travels along the midline anterior pons, and terminates near the pontomesencephalic junction. During its course, the artery branches prolifically, providing several perforating arteries (classified by distribution as either paramedian or circumferential) to the pons, the anterior inferior cerebellar and superior cerebellar arteries (AICAs and SCAs, respectively) to a broad cerebellar territory, and then supplies much of the posterior cortical surface through its terminal split into the posterior cerebral arteries (PCAs). As is readily appreciable due to the vastness of this vascular area, lesions of the basilar artery are, although uncommon, very grave in

prognosis: a mortality rate of 85% has been reported of basilar artery occlusions. The symptomology of survivors, moreover, can also be quite grave. A condition known as locked-in syndrome can occur, in which patients are quadriplegic and incapable of either speech or horizontal eye movements, but are nevertheless conscious. (Chandra, A *et al.*, 2017)

2.2.1.5.1 Perforating branches of the basilar artery (pontine branches)

These arteries are small, numerous, basilar branches that collectively provide a substantial contribution to the complex vascular territory of the pontine brainstem. When categorized according to distribution, they fall into two classes. The first class, referred to as paramedian, extends immediately from the basilar artery into the substance of the pons and supplies structures located relatively close to midline, such as the corticospinal tract. The second class is called circumflex, due to its more lateral distribution, which extends its longest branches all the way around to the dorsal aspect of the pons as posterior pontine arteries. (Chandra, A *et al.*, 2017)

2.2.1.5.1. Anterior inferior cerebellar artery

This artery is the first large branch of the basilar artery and has an analogous direction of course to the more caudally positioned PICA. It generally proceeds from the caudal one-third of the basilar artery, traveling laterally along the middle cerebellar peduncle to reach the cerebellum. In addition to typically supplying the petrosal surface of the cerebellum, it also supplies a subregion of the pontine brainstem that includes the middle cerebellar peduncle, and the central portions of several sensory pathways, as evidenced by the ability of AICA lesions to mimic schwannomas of the vestibular, facial, and trigeminal nerves. AICA also usually gives rise to the labyrinthine artery of the inner ear, which perhaps helps account for the deafness lesions in this artery can also produce. (Chandra, A *et al.*, 2017)

2.2.1.5.2. Superior cerebellar artery

This artery may be thought of as, like AICA, another PICA analog. The final, nonterminal branch of the basilar artery, SCA runs laterally over the superior cerebellar peduncle, supplying the peduncle itself and, by way of spreading medial and lateral branches, much of the superior surface of the cerebellum. It also supplies the deep nuclei embedded within the cerebellar white matter, and a brainstem region adjacent to the rostral pontine tegmentum. (Chandra, A *et al.*, 2017)

2.2.2.5.3. Posterior cerebral artery

The final posterior circulation contribution to consider is that provided by the posterior cerebral arteries. These arteries usually arise bilaterally from the terminal bifurcation of the basilar arteries but have been found to originate unilaterally at the ICA in between 11% and 29% of cases examined. This is a clinically consequential variant: it can mimic cerebrovascular pathology on perfusion MRI due to an asymmetric signature. In any case, after splitting from the basilar artery or otherwise, the PCA encircles the midbrain at the pontomesencephalic junction, immediately rostral to the root of the third (oculomotor) cranial nerve. (Chandra, A *et al.*, 2017)

Along its posterior passage, it travels over the cerebral peduncles, and thence to the ventromedial surface of the cortex, thus through an elaborate pattern of branches constituting a major source of blood to the occipital lobe, the inferior and medial parts of the temporal lobe, and a posterior portion of the inferior parietal lobe. As has been the case in every example mentioned above, the cortical symptoms produced by PCA infarcts are consistent with the functions of the artery's territory: most commonly (84%–100%), such infarcts produce visual field deficits, but alexia and agnosias can also occur, such as, owing to fusiform gyrus dysfunction, prosopagnosia. PCA also has a substantial subcortical territory that covers the thalamus, midbrain, and choroid plexus; deep areas have been found to be involved in almost 30% of pure PCA infarcts.[63] Like

the ACA and MCA of the anterior circulation, the PCA has been divided into segments by location along its extent, but we will not discuss these further. The interested reader may refer to our sources. (Chandra, A *et al.*, 2017)

2.2.1.2. The Venous System

Therefore the cerebral venous system is not to be discussed in this study. Arterial system is often given more attention than its venous counterpart due to its relevance of to the topic of ischemic stroke.

2.3 Classification of stroke (based on etiology):

Stroke is classified on the basis of its etiology as either ischaemic (80%) or haemorrhagic (20%). Ischaemic stroke is produced by occlusion of a cerebral artery [thrombotic or atherosclerotic (50%), embolic (25%) and microartery occlusion, "lacunar stroke", (25%)]. Haemorrhagic stroke is caused mainly by spontaneous rupture of blood vessels or aneurysms or secondary to trauma. (Wittenauer, R. and Smith, L., 2012)

2.3.1 Ischemic stroke

Neurological symptoms and signs of an ischemic stroke usually appear suddenly, but less frequently, they occur in a progressive manner (stroke-in-progress). The typical presentation is the sudden onset of hemiparesis in an older person. Symptoms and signs vary depending on the location of the occlusion and the extent of the collateral flow. (Wittenauer, R. and Smith, L., 2012)

2.3.1..1. Atherosclerotic ischaemic stroke

It is commoner in the elderly, and occurs without warning in more than 80% of cases. A TIA a few months before the stroke is considered an important warning sign. The pathophysiology is similar to that of ischaemic heart disease; an atherosclerotic plaque

in a cerebral artery ulcerates triggering the aggregation of platelets and coagulation of fibrin to produce the thrombus that occludes the artery. Fewer than 20% of cases do not evolve to ulceration, but progresses to cause gradual obstruction of flow and may manifest as TIAs. In hypertension-induced arteriosclerosis, small penetrating arteries of the deep white matter of the brain are affected producing small infarctions known as "lacunar infarcts". In around 40% of elderly stroke patients no clear origin of the infarction can be found. (Wittenauer, R. and Smith, L., 2012)

2.3.1.2. Embolic ischaemic stroke

It is more frequent in patients with atrial fibrillation (80%), myocardial infarction, prosthetic valves, rheumatic heart disease and larger artery atheroma (artery-artery embolus). Most emboli are of atherosclerotic origin, and may partially or temporally obstruct cerebral arteries causing TIAs.5 Embolisms tend to be multifocal and may produce small haemorrhages around the obstruction. The occlusion of a cerebral artery causes a decreased blood flow and ischaemia. If it lasts only few seconds or a minute, recovery is immediate and complete. Depending on the severity of the ischemia, infarction (cellular death) will occur within minutes, causing irreversible damage even after blood flow is restored. This is called the "core" of the infarct. Surrounding the core is tissue that is affected functionally due to diminished circulation but may recover if blood flow is restored.6-18 This is called the "ischaemic penumbra" of a stroke. Most people will have an ischaemic penumbra amenable to treatment for 3 hours, but many patients may have it up to 12 hours. This is known as the 'therapeutic window' available for thrombolysis. Thus proper identification of treatable patients is crucial for the efficacy of the interventions. Due to changes in the vessels and parenchyma caused by ischaemia, the flow may not be restored even after the original cause of the obstruction has been removed ("no-reflow phenomenon"). Oedema is present in all necrotic tissue. In large areas of necrosis, massive oedema compresses adjacent tissue, increasing

intracranial pressure and may cause herniation of the brain, leading to death within a few days in 80% of cases.19-23 Surgical decompression has been suggested for these cases. The extent of functional disability will depend on the extent and the localization of ischaemia and complications experienced by the patient. Seizures at the time of stroke occur in 3–5% of infarctions, more often after embolism than thrombosis. The same proportion of patients will develop epilepsy from 6 to 18 months after a stroke. Idiopathic epilepsy in the elderly, therefore, may be the result of silent cortical infarction. (Wittenauer, R. and Smith, L., 2012)

2.3.2 Haemorrhagic stroke

There are two types; one resulting from intracerebral haemorrhage secondary to hypertension or cerebral amyloid angiopathy, degenerative arterial disease and the other secondary to subarachnoid haemorrhages caused by rupture of an aneurysm. In the United States, 8–10 million people (3% prevalence) might have one aneurysm and bleeding occurs in only 30 000 people per year. Other causes are uncommon, and sometimes, no source for the haemorrhage can be found. The main risk factors are advanced age, heavy alcohol consumption and hypertension. Cocaine abuse is an important cause of cerebral haemorrhage in young people. Most intracerebral haemorrhagic strokes develop over 30–90 min. Symptoms will depend on the location and extent of the haemorrhage. Focal neurological symptoms, vomiting and drowsiness are common. Headache may be present, but stiff neck and seizures are uncommon. Large haemorrhages may cause stupor or coma. Most sub-arachnoid haemorrhages appear suddenly with intense headache, vomiting and neurological deficit and altered consciousness may occur in about 50% of patients. Occasionally, prodromal neurological symptoms, such as paralysis of a limb, difficulty in speaking, visual impairment or sudden unexplained headache, appear before a haemorrhage from an enlarging aneurysm causing pressure on the surrounding tissue or as a result of a leak of blood into the subarachnoid space (“warning leaks”). Cerebral vasospasm is an early

complication and re-bleeding or hydrocephalus may be complications of SAH in 30% of cases during the first month, resulting in an extra 60% mortality. Of those who survive, more than half will have significant disabilities. The annual risk of recurrence of bleeding of an aneurysm is 3%. Thus, early surgical or intravascular treatment of aneurysm in these patients improves their long term outcome. (Wittenauer, R. and Smith, L., 2012)

2.4 Pathophysiology

Ischaemic stroke usually occurs due to occlusion of a cerebral artery, or less often a reduction in perfusion distal to a severe stenosis. As cerebral blood flow falls, neuronal function is affected in two stages. Initially, as blood flow falls below a critical threshold of about 20 ml blood/100 g brain/min (normal being over 50 ml/100 g/min), loss of neuronal electrical function occurs. Crucially, this is a potentially reversible stage. Irreversible damage occurs within minutes as blood flow falls below a second critical threshold of 10 ml/100 g/min; below this level, aerobic mitochondrial metabolism fails, and the ineYcient anaerobic metabolism of glucose takes over, rapidly leading to lactic acidosis. Consequently, the normal energy dependent cellular ion homeostasis fails, resulting in potassium leaking out of the cell, and sodium and water entering the cell, leading to cytotoxic oedema. Calcium also enters the cell, exacerbating mitochondrial failure. This loss of cellular ion homeostasis leads to neuronal death. The identification of these two stages of neuronal failure has led to the concept of the ischaemic penumbra—that is, an area of brain which has reached the reversible stage of electrical failure, but has not yet passed onto the second irreversible stage of cellular homeostatic failure. In theory therefore, this tissue could be “rescued”, either by early reperfusion (using agents to dissolve the acute thrombotic lesion and restore normal blood flow), or by administering agents which could protect these potentially viable neurons from further damage (neuroprotection); the combination of reperfusion and neuroprotection would seem a logical conclusion. (Wittenauer, R. and Smith, L., 2012)

2.5 Complications of acute stroke:

STROKE PATIENTS MAY REQUIRE IMMEDIATE TREATMENT

There are several reasons why many patients require urgent inpatient care after an acute stroke. Firstly, stroke may lead to various potentially life threatening complications such as: airway obstruction and respiratory failure, swallowing problems with the risk of aspiration, dehydration and malnutrition, venous thromboembolic complications, seizures, and infections. These may arise within hours of stroke onset and require early assessment and intervention so that they can be anticipated, prevented, and treated. (Davenport, R. and Dennis, M., 2000)

2.6 Diagnosis and investigation of acute stroke

Radiographic imaging studies and other laboratory testing are aimed at answering these questions in the evaluation of acute stroke:

(1) Is the lesion(s) in the CNS caused by ischemia or hemorrhage, or is it related to a nonvascular stroke mimic?

(2) Where is the lesion(s)? What is its size, shape, and extent?

(3) What is the nature and severity of the vascular lesion(s), and how do the vascular lesion(s) and brain perfusion abnormalities relate to the lesion(s)? and

(4) Are abnormalities of blood constituents causing or contributing to ischemia or hemorrhage? Confirmation that the patient has had a stroke and not a stroke mimic depends heavily on brain imaging. (Sacco RL *et al.*, 2013)

2.6.1 Radiographic diagnosis

Computed tomography (CT) scanning is usually able to exclude stroke mimics such as brain tumors and subdural hematomas and to separate brain ischemia from hemorrhage. Brain imaging with CT or MRI can localize the regions of brain infarction and hemorrhage. However stroke infarcts in the hyperacute state are less seen in CT imaging. Imaging of the cervical and intracranial arteries and veins, focusing on those that supply the region of vascular injury, can identify occlusive vascular lesions and show vascular malformations and aneurysms. Vascular imaging can be performed using **ultrasound (duplex Doppler imaging** of the blood vessels in the neck and transcranial Doppler study of intracranial arteries), or by CT or magnetic resonance angiography or by **catheter angiography**. Traditional ideas that a strict brain time window exists for acute stroke differ from modern imaging findings obtained by methods such as MRI diffusion-weighted imaging (DWI), which highlights tissue changes after several minutes to days after transient or permanent ischemic events. A recent Cochrane review of CT and MRI for the diagnosis of acute cerebral infarction within 12 hours of symptom onset showed that the pooled estimates for CT sensitivity and DWI MRI sensitivity were 0.39 and 0.99, respectively, using a clinical diagnosis as the reference standard. In stroke patients, imaging of the brain with CT or T2- weighted (T2-w) MRI is an important tool to distinguish between hemorrhagic and nonhemorrhagic stroke. Once the presence of an intracranial hemorrhage is excluded, imaging can also help to classify the stroke subtype by determining the site and size of the ischemic lesion. MRI is the modality of choice when it comes to diagnosing acute nonhemorrhagic strokes, as it has the ability to detect ischemic strokes earlier than CT in which it can only be detected 48 hrs after the onset. (Sacco RL *et al.*, 2013)

2.7 Magnetic Resonance Imaging in Stroke

Magnetic resonance imaging (MRI) provides non-invasive information about the brain's blood flow, water movement and biochemical abnormalities following stroke, and advances in MRI are transforming the investigation and treatment of cerebrovascular disease. Echoplanar techniques with diffusion- and perfusion-weighted imaging, together with developments in magnetic resonance spectroscopy and angiography, are replacing CT scanning as the diagnostic modality of choice. (Sacco RL *et al.,* 2013)

2.7.1 Diffusion-weighted imaging (DWI)

Diffusion-weighted Magnetic Resonance (MR) imaging (DWI) is an advanced MR imaging technique, which allows non-invasive evaluation of water diffusibility in brain tissue. The primary application of DWI has been in brain imaging, mainly because of its high sensitivity to ischemic stroke — a common condition that appears in the differential diagnosis in almost all patients who present with a neurologic complaint.

Diffusion-weighted MRI (DWI) provides potentially unique information on the viability of brain tissue. It provides image contrast that is dependent on the molecular motion of water, which may be altered markedly by disease. It also demonstrates areas with restricted diffusion of extracellular water such as infarcted tissue. In normal tissue, extracellular water diffuses randomly whereas in ischaemic tissue, cells swell and absorb water thereby reducing average diffusion. In DWI, the sequence can be sensitized to diffusion by applying equal gradients on each side of a 180° RF pulse. Hence, diffusion-weighted images are most effectively acquired using SE-type sequences such as SE or SE-EPI. These gradient pulses are designed to cancel out the phase shift of stationary spins whilst moving spins experience a phase shift. Therefore, signal attenuation occurs in normal tissue with random motion, and high signal appears in tissues with restricted diffusion. The amount of attenuation depends on the amplitude of the gradients which is altered by selection of a b-value (expressed as s/mm2). Gradient pulses can be applied

along the X, Y and Z axes to determine the axis of restricted diffusion. The term isotropic diffusion is used to describe diffusion gradients applied in all three axes. DWI is mainly useful in the brain to differentiate salvageable and non-salvageable tissue after stroke. It is also useful in the liver, prostate, spine and bone marrow. (Westbrook C, 2014)

2.8 Diffusion-weighted imaging (DWI) for the assessment of acute stroke

DWI is more accurate than CT in localizing ischemic lesions shortly after stroke onset. Admission CT does localize lesions correctly in only 53% of patients. On the other hand, conventional MRI correctly identifies acute cerebral ischemia in 71% to 80% of cases. With the addition of DWI, this percentage increases to 94%. Interobserver agreement is better in DWI than in conventional MRI. DWI can show small lesions adjacent to the cerebrospinal fluid. The diagnosis of a small cortical or brainstem infarct may be difficult on T2–WI images while DWI (Figs. 4–6) easily depicts such lesions.
Fluid attenuated inversion recovery (FLAIR) demonstrates similar sensitivity to ischemic lesions than DWI, but does not allow demonstration of early lesions and differentiation between new and old lesions. (Van Everdingen, K.J. *et al.*, 1998)

2.9 Previous studies

Patients with cerebrovascular diseases often have multiple ischemic lesions seen on conventional MR examination at the time of their first symptomatic event. In our registry, among 1000 consecutive patients with first-ever stroke, 3% show infarcts in multiple territories supplied by carotid arteries, 2% display multiple infarcts in the vertebrobasilar territory, whereas 2% show multiple infarcts in both territories. Embolism arising from aortic branch vessel atheromatosis and cardiac origin is the main cause of multiple cerebral infarcts. Whether the latter is the result of the fragmentation of a single embolism, or whether it causes multiple territory infarction by proximal

occlusion of major vessels with distal hemodynamic infarction still remains unclear. Among patients with multiple cerebral ischemic lesions, 30% show multiple acute infarcts, 56% single acute infarct and multiple old infarcts, and 14% multiple acute and multiple old infarcts. One limitation of conventional MR imaging is that acute and old infarcts appear very similar. T2- weighted images do not allow for differentiation of acute vs. chronic infarcts, whereas T1-weighted images with gadolinium enhancement are helpful in only 12% of patients. This can cause diagnostic confusion regarding which lesion is acute and symptomatic, even with the help of neurological findings, especially in elderly patients whose conventional MR examination demonstrates a large number of high-signal foci in the corona radiata, basal ganglia and brainstem on T2-weighted images. Moreover, in such patients, it may be difficult to determine whether new neurological symptoms represent a new ischemic event, or just the unmasking of a prior deficit due to an intercurrent illness. (Van Everdingen, K.J. *et al.*, 1998)

DWI overcomes conventional MR imaging limitations. Indeed, DWI can easily distinguish between new and old ischemic brain injuries. On the other hand, both are hyperintense on the DWI trace, which, however, affords sharp delineation of pathologic processes through the removal of anisotropy of myelin fibres and the absence of contrast between grey and white matter. In 77% to 100% of patients with multiple cerebral infarcts, DWI not only delineates early ischemic brain injury better than conventional MR, but also successfully identifies the acute lesion responsible for the clinical deficit. Moreover, in 18% of acute stroke patients, DWI has been reported to localize the symptomatic lesion in a different vascular territory from the one suspected, which relied upon the combination of the initial clinical evaluation and the conventional MR examination. Finally, in 20% of acute stroke patients, DWI allowed to make clear that lesions thought to be acute on the conventional MR sequences were actually old. (Van Everdingen, K.J. et al., 1998)

Chapter Three

MATERIALS AND METHODOLOGY

Chapter Three

3. Materials and Methodology

3.1 Meterials

MRI machine (1.5Tesla), head RF (radiofrequency) coils, immobilization pads and headphone were used for the examination.

3.1.1 Study design

This is an experimental study that was carried out on 30 patients, 19 males and 11 females, age range between 18 and 86 years. They were presented with one or more of neurologic symptoms suggestive of cerebrovascular stroke.

Patients were assessed clinically in the emergency room and were referred to the radi-diagnosis department for MRI examination of the brain. The time between the onset of symptoms and the MRI investigation ranged from 2–72 h). Eight patients were imaged by CT scan first where no infarcts were visible on their images, but they were clearly seen on MRI which indicates that they were patients in the acute state of stroke.

The sizes of brain infarcts on T1WI, T2WI, FLAIR and DWI of the whole sample were measured as listed in Table 3.

3.1.2 Study area

Brain MRI scans was performed at Antalya and Al-zaytoona hospitals in Khartoum.

3.1.3 Study duration

This study was conducted during the period from July 2020 until August 2020.

3.1.4 Study population

This study will include population from modern medical centers in Khartoum, Sudan who presented with one or more of neurologic symptoms suggestive of cerebrovascular stroke.

3.1.5 Sample size

30 patients, including 20 males and 10 females.

3.2 Methodolgy

3.2.1 Preparation of patients

- A satisfactory written consent was taken from patients before entering the scanner room.
- Any type of contraindications for MRI were checked such as; pregnancy, ferromagnetic surgical objects..etc.
- Patients were asked to remove all metal objects.
- Procedure was explained and earplugs were offered before starting the scan.
- Weight was noted.
- Patients were instructed to keep still.

3.2.2 Imaging protocol

Three planes localizer, axial (T1WI), axial (T2WI), axial (FLAIR), axial DWI.

3.2.3 Technique

The patient lay supine with the head first in the gantry using a head coil. The three-plane localizer (scout) includes axial, coronal, and sagittal images, matrix size 128 × 128 ms, slice thickness 5 mm, inter-slice gap 0.5 mm (FLAIR=1.5), and field of view 26 × 26.
Axial T1WI, echo time (TE): 11 ms. Repetition time (TR): 520 ms. Axial T2WI, TE: 135 ms, TR: 2900 ms. Axial FLAIR, TE: 120 ms, TR: 8002 ms. Inversion time = 2000 ms. Axial DWI, TE: 114 ms, TR: 7000 ms. B-value: 1000 s/mm2.
All the image sequences were reported carefully to identify any signal abnormalities. The size of the lesions was measured as length × width in cm.

Chapter Four

RESULTS

Chapter Four

4. Results

4.1. Demographic and clinical data of all study population:

The results were analyzed of 30 patients, 19 men and 11 women, mean age 56 years and range 18–86 years; with a higher incidence rate in males rather than females (63.33% to 36.67%, respectively).

They presented with signs and symptoms suggestive of acute stroke such as numbness, disturbed level of consciousness, ataxia, and blurring of vision.

The mean time between the onset of symptoms and the MRI investigation ranged from (2–72 h).

Hyperintense signals on T1WI, T2WI, FLAIR, and DWI indicates the presence of cerebral infarction.

Conventional T1W1 detected infarctions in 9/30 patients (30%), T2WI detected infarctions in 19/30 patients (63%) and FLAIR detected infarctions in 26/30 patients (86%).

DWI showed the highest sensitivity as it identified the lesions in all 30 patients.

The size of the lesions was measured on DWI and FLAIR scans; within 2 h of stroke onset to 3 days after the onset of stroke (Table 5).

The mean lesion size (length × width) in cm was larger on the DWI scans (2.2 × 1.8 cm) than on FLAIR images (1.9 × 1.8 cm).

Table (4.1): Mean size (length × width) of infarctions detected as seen on FLAIR and DWI, DWI, diffusion-weighted MRI; FLAIR, fluid-attenuated inversion recovery

No.	Gender	Age(years)
1	M	36
2	F	40
3	F	76
4	F	70
5	M	65
6	M	60
7	M	55
8	M	54
9	M	52
10	M	85
11	F	86
12	F	64
13	M	20
14	M	38
15	M	37
16	M	34
17	F	46
18	F	46
19	F	75
20	F	70
21	F	68
22	M	58
23	M	50
24	F	33
25	M	65
26	M	63
27	M	60
28	M	59
29	M	60
30	M	55

Figure (4.1): Chart shpwing the incidence rate of acute stroke in the study sample

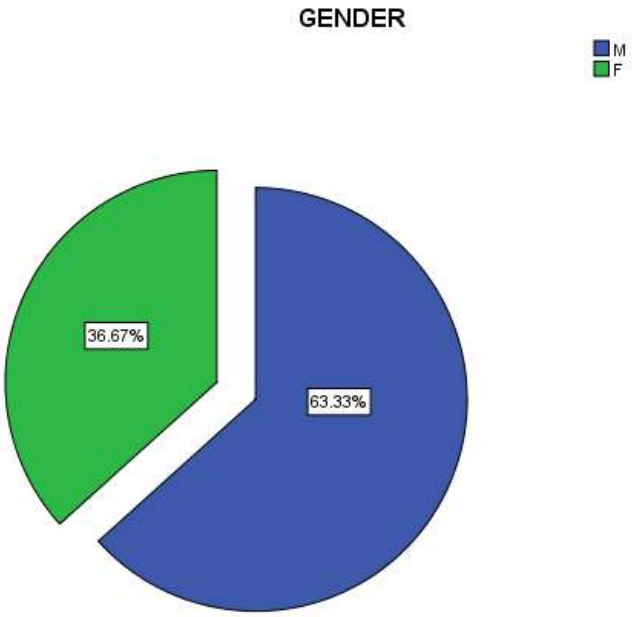

Figure (4.2): Chart showing the age ranges of the study sample

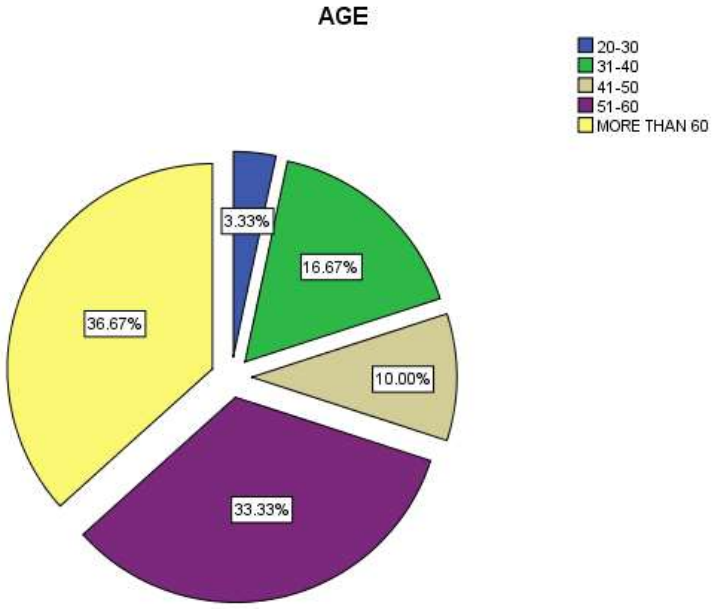

Table (3.2): Time of sequences used on MR imaging

Sequences	Time
Axial T1WI	1 min and 30 sec
Axial T2WI	55 sec
Axial FLAIR	1 min and 12 sec
Axial DWI	54 sec

DWI (diffusion-weighted imaging), FLAIR (fluid-attenuated inversion recovery),T1WI (T1-weighted imaging), T2WI (T2-weighted imaging).

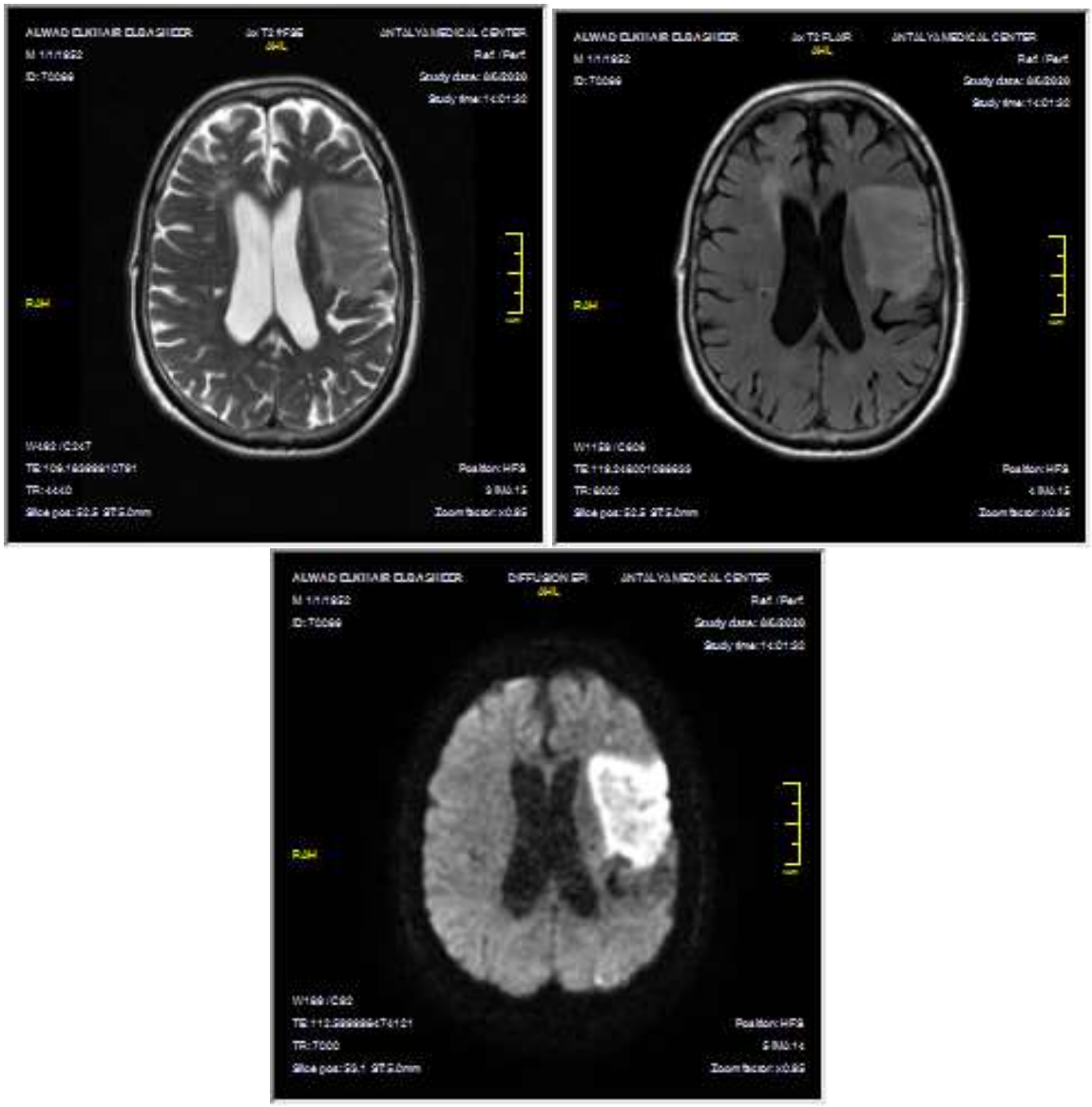

Figure (4.3): Hyperintense signal on T2, FLAIR, and DWI observed at the left temporal and occipital region. DWI, diffusion-weighted MRI; FLAIR, fluid-attenuated inversion recovery.

Table (3.1): The sizes of brain infarcts on T1WI, T2WI, FLAIR and DWI of the whole sample

No.	Gender	Age(years)	T1(cm)	T2(cm)	FLAIR(cm)	DWI(cm)
1	M	36	Not detected	Not detected	1.7*0.6	1.7*0.7
2	F	40	Not detected	1.3*0.6	1.3*0.6	1.5*0.6
3	F	76	Not detected	0.9*0.5	1.0*0.4	1.0*0.5
4	F	70	Not detected	1.1*0.5	1.1*0.6	1.4*0.9
5	M	65	Not detected	Not detected	1.7*0.7	0.9*0.5
6	M	60	Not detected	1.1*0.7	1.2*0.8	1.5*0.7
7	M	55	Not detected	Not detected	0.8*0.5	0.9*0.6
8	M	54	Not detected	Not detected	0.7*0.4	0.7*0.5
9	M	52	8.0*2.5	11.0*4.9	11.7*4.8	12.1*4.9
10	M	85	0.7*0.7	1.7*0.8	1.8*0.8	2.8*1.3
11	F	86	1.1*0.8	1.8*1.3	3.0*1.9	3.6*2.0
12	F	64	Not detected	1.7*2.0	1.9*2.1	1.9*2.2
13	M	20	Not detected	Not detected	1.0*1.0	1.0*0.7
14	M	38	2.8*2.4	2.3*1.7	2.1*1.8	2.3*3.1
15	M	37	2.3*2.4	1.8*2.4	1.7*2.0	2.0*2.0
16	M	34	3.2*3.3	3.1*2.7	2.8*2.8	2.5*3.2
17	F	46	Not detected	2.0*1.5	1.9*1.7	1.7*1.5
18	F	46	Not detected	2.3*2.5	2.1*2.5	1.6*2.4
19	F	75	Not detected	2.8*0.8	Not detected	1.8*0.7
20	F	70	Not detected	1.5*1.5	1.3*1.5	4.8*3.3
21	F	68	Not detected	Not detected	Not detected	0.7*1.1
22	M	58	3.2*1.7	5.3*3.1	5.8*3.2	4.9*2.8
23	M	50	Not detected	Not detected	1.1*0.8	1.6*3.2
24	F	33	1.3*0.9	3.1*1.5	3.2*1.6	3.0*1.4
25	M	65	Not detected	1.2*2.3	1.2*2.8	1.3*2.9
26	M	63	Not detected	Not detected	Not detected	2.3*2.3
27	M	60	1.6*0.9	2.0*2.0	2.0*2.2	1.4*1.9
28	M	59	Not detected	Not detected	1.2*6.6	1.9*1.4
29	M	60	Not detected	Not detected	Not detected	1.4*2.1
30	M	55	Not detected	Not detected	1.3*1.7	1.2*1.1

M: male, F: female, size=length*width, DWI (diffusion-weighted imaging), FLAIR (fluid-attenuated inversion recovery),T1WI (T1-weighted imaging), T2WI (T2-weighted imaging).

Chapter Five

DISCUSSION, CONCULSION AND RECOMMENDATIONS

Chapter Five

5. DISCUSSION, CONCULSION AND RECOMMENDATIONS

5.1. Discussion

Our study included 19 men and 11 women, mean age 56 years, ranging from 18 to 86 years. A higher incidence of acute stroke was found among men than women (Figure 5.1). The study by Evan Everdingen et al. (Evan Everdingen KJ *et al.,* 1998) [96] on 25 men and 17 women and the study by Roquer et al. (Roquer J *et al*., 2003) [97] on 809 men and 772 women reported results that were in agreement with ours, that men are more prone to acute stroke probably because of overstress, smoking, and peripheral vascular disease, which are more common in men than women.

The time range between the onset of symptoms and the early MR investigations in our study was from 1 hr to 72 hrs). In the study by Lansberg et al. (Lansberg MG *et al.,* 2000) [98], the baseline MRI scan was performed at a mean of 29 ± 15 h after the onset of symptoms. Overall, 5/49 patients underwent scanning within 12 h after the onset of symptoms. In the study by Nakamuraa et al. (Nakamuraa H *et al.,* 2005) [99], the interval between stroke onset and MRI examination ranged from 2 h to 8 days.

A study by Huang et al. (L Huang *et al.,* 2001) included 70 patients with cerebral infarction. The results showed that eight hyperacute cerebral ischemic infarctions were diagnosed by DWIs, but not detected by T2WIs. This shows that DWI have greater sensitivity for acute, especially hyperacute cerebral infarction than T2WI.

The study by Abdul Sattar et al. (A Sattar et al., 2012) reported that in 117 patients, the DWI was more sensitive than FLAIR in the detection of stroke during the first 6 h; it was still superior to FLAIR even after 24 h. In the hyperacute period after stroke, FLAIR could detect only 29% of the acute ischemic strokes that were identified by DWI.

The study by Thomalla (Thomalla G *et al.*, 2009) on 120 patients examined by DWI and FLAIR within 6 h of symptom onset showed a 'mismatch' between DWI and FLAIR as the acute ischemic lesions were visible on DWI, but not on FLAIR; this mismatch indicated lesions within less than 3 h. FLAIR imaging proved even superior to T2WI in the detection of ischemic lesions.

The study by (Schaefer *et al*., 2000) reported that computed tomography and MRI cannot reliably detect infarction at early onset. DW images are very sensitive and specific for the detection of hyperacute and acute infarctions. The study also reported that the majority of stroke lesions increase in volume on DW images, with the maximum volume achieved after 2–3 days. Our results are in agreement that DWI is a useful imaging method to detect ischemic lesions in the acute stage (1 h to 3 days after onset) of stroke. All the infarcts, 30/30 (100%), were found to be hyperintense on DWI. The final clinical diagnosis of these patients was acute cerebral stroke. Of 30 patients who underwent conventional MRI in acute stages, only 19 patients (63%) were diagnosed with cerebral infarcts on T2WI. FLAIR imaging could diagnose 26 cases of infarcts (86%). Although less accurate than DWI, FLAIR imaging provided better results in detecting ischemic lesions than conventional MRI. In terms of the size of the lesions, they were larger on DWI scans than on FLAIR images. Our results are in agreement with the study by (Evan Everdingen *et al*., 1998) and (Schaefer *et al*., 2000)

5.2 Conclusion:

MRI is an efficient examination that can rapidly diagnose stroke and therefore provide better management for the patient. In the acute stages, the ischemic lesions appear hyperintense on DWI and. DWI showed considerable superiority in detecting acute ischemic lesions than T1WI, T2WI, and FLAIR.

DWI is a useful technique in detecting ischemic lesions at different stages. However, FLAIR is superior to T1WI and T2WI in acute stroke. The size of the lesions in patients who were imaged within 1-72 hrs after the onset of cerebral stroke were mostly larger on DWI scans than on FLAIR images. Therefore, MRI is strongly recommended for the accurate diagnosis of acute stroke.

5.3 Recommendations

Based on the other findings of the present study and the limitations it is recommended that is DWI allows the detection of acute ischemic lesions within minutes, but does not allow any further conclusions on lesion age during the initial hours of stroke. T2 signal changes might allow further timely allocation of ischemic lesions as ischemic lesions become visible on T2WI within the first hours of stroke onset. (Bai, Q., et al., 2013)

5.4 References

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5.5 Appendices
(A)

Table (1): Mean size (length × width) of infarctions detected as seen on FLAIR and DWI, DWI, diffusion-weighted MRI; FLAIR, fluid-attenuated inversion recovery

No.	Gender	Age(years)	FLAIR(cm)	DWI(cm)
1	M	36	1.7*0.6	1.7*0.7
2	F	40	1.3*0.6	1.5*0.6
3	F	76	1.0*0.4	1.0*0.5
4	F	70	1.1*0.6	1.4*0.9
5	M	65	1.7*0.7	0.9*0.5
6	M	60	1.2*0.8	1.5*0.7
7	M	55	0.8*0.5	0.9*0.6
8	M	54	0.7*0.4	0.7*0.5
9	M	52	11.7*4.8	12.1*4.9
10	M	85	1.8*0.8	2.8*1.3
11	F	86	3.0*1.9	3.6*2.0
12	F	64	1.9*2.1	1.9*2.2
13	M	20	1.0*1.0	1.0*0.7
14	M	38	2.1*1.8	2.3*3.1
15	M	37	1.7*2.0	2.0*2.0
16	M	34	2.8*2.8	2.5*3.2
17	F	46	1.9*1.7	1.7*1.5
18	F	46	2.1*2.5	1.6*2.4
19	F	75	Not detected	1.8*0.7
20	F	70	1.3*1.5	4.8*3.3
21	F	68	Not detected	0.7*1.1
22	M	58	5.8*3.2	4.9*2.8
23	M	50	1.1*0.8	1.6*3.2
24	F	33	3.2*1.6	3.0*1.4
25	M	65	1.2*2.8	1.3*2.9
26	M	63	Not detected	2.3*2.3
27	M	60	2.0*2.2	1.4*1.9
28	M	59	1.2*6.6	1.9*1.4
29	M	60	Not detected	1.4*2.1
30	M	55	1.3*1.7	1.2*1.1

Table (2): The sizes of brain infarcts on T1WI, T2WI, FLAIR and DWI of the whole sample

No.	Gender	Age(years)	T1(cm)	T2(cm)	FLAIR(cm)	DWI(cm)
1	M	36	Not detected	Not detected	1.7*0.6	1.7*0.7
2	F	40	Not detected	1.3*0.6	1.3*0.6	1.5*0.6
3	F	76	Not detected	0.9*0.5	1.0*0.4	1.0*0.5
4	F	70	Not detected	1.1*0.5	1.1*0.6	1.4*0.9
5	M	65	Not detected	Not detected	1.7*0.7	0.9*0.5
6	M	60	Not detected	1.1*0.7	1.2*0.8	1.5*0.7
7	M	55	Not detected	Not detected	0.8*0.5	0.9*0.6
8	M	54	Not detected	Not detected	0.7*0.4	0.7*0.5
9	M	52	8.0*2.5	11.0*4.9	11.7*4.8	12.1*4.9
10	M	85	0.7*0.7	1.7*0.8	1.8*0.8	2.8*1.3
11	F	86	1.1*0.8	1.8*1.3	3.0*1.9	3.6*2.0
12	F	64	Not detected	1.7*2.0	1.9*2.1	1.9*2.2
13	M	20	Not detected	Not detected	1.0*1.0	1.0*0.7
14	M	38	2.8*2.4	2.3*1.7	2.1*1.8	2.3*3.1
15	M	37	2.3*2.4	1.8*2.4	1.7*2.0	2.0*2.0
16	M	34	3.2*3.3	3.1*2.7	2.8*2.8	2.5*3.2
17	F	46	Not detected	2.0*1.5	1.9*1.7	1.7*1.5
18	F	46	Not detected	2.3*2.5	2.1*2.5	1.6*2.4
19	F	75	Not detected	2.8*0.8	Not detected	1.8*0.7
20	F	70	Not detected	1.5*1.5	1.3*1.5	4.8*3.3
21	F	68	Not detected	Not detected	Not detected	0.7*1.1
22	M	58	3.2*1.7	5.3*3.1	5.8*3.2	4.9*2.8
23	M	50	Not detected	Not detected	1.1*0.8	1.6*3.2
24	F	33	1.3*0.9	3.1*1.5	3.2*1.6	3.0*1.4
25	M	65	Not detected	1.2*2.3	1.2*2.8	1.3*2.9
26	M	63	Not detected	Not detected	Not detected	2.3*2.3
27	M	60	1.6*0.9	2.0*2.0	2.0*2.2	1.4*1.9
28	M	59	Not detected	Not detected	1.2*6.6	1.9*1.4
29	M	60	Not detected	Not detected	Not detected	1.4*2.1
30	M	55	Not detected	Not detected	1.3*1.7	1.2*1.1

M: male, F: female, size=length*width, DWI (diffusion-weighted imaging), FLAIR (fluid-attenuated inversion recovery),T1WI (T1-weighted imaging), T2WI (T2-weighted imaging).

Appendices (B)
Figures

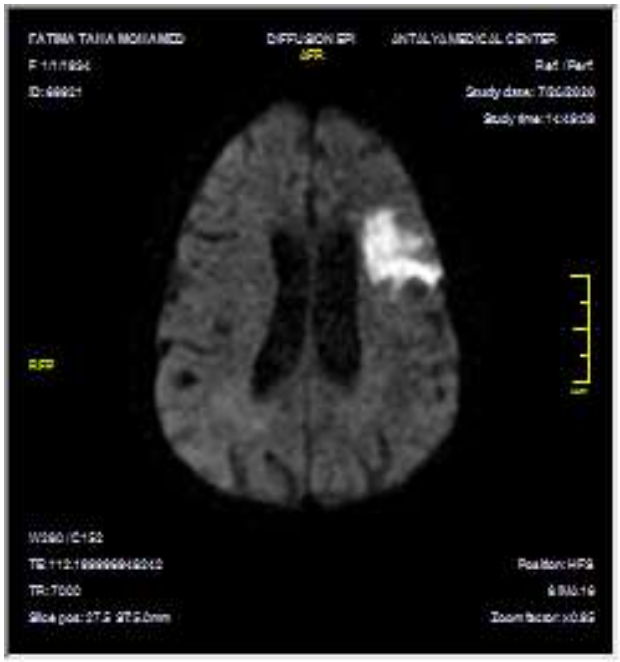
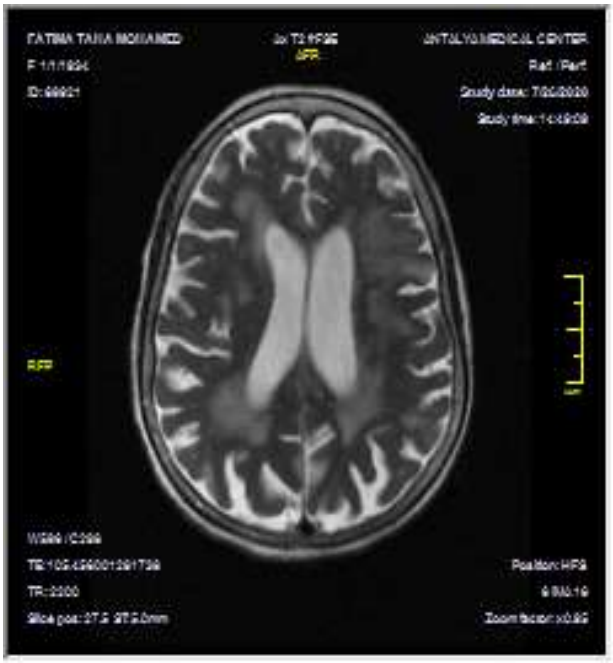
(a)  (b) 

Figure (1): Case study 10: Left temporal acute infarction detected in DWI, and T2WI of a 86-year-old female patient. MR images were obtained 10 h after the onset of symptoms. (a) A bright signal lesion at the lateral part of the left temporal region on the DW image. (b) a low signal at the same site. DWI: diffusion-weighted MRI; T2WI: T2-weighted imaging.

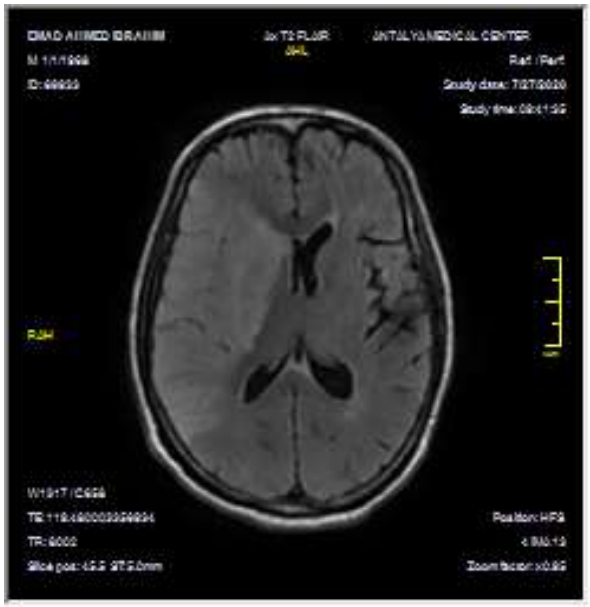
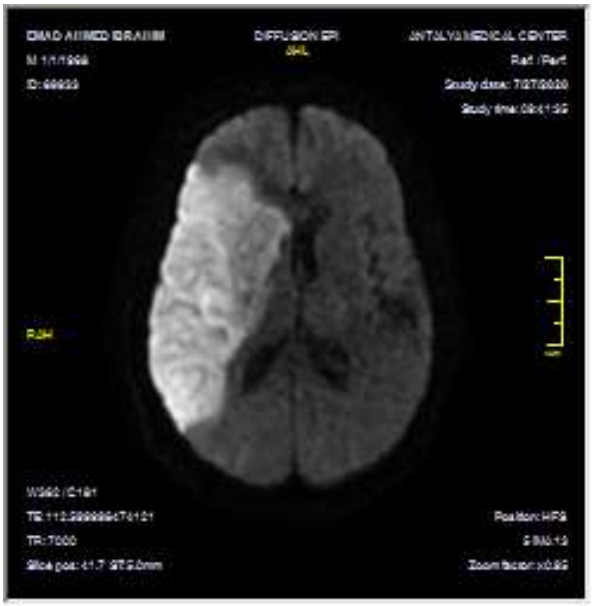
(a)  (b) 

Figure (2): Case study 11: Right cerebellar hemisphere acute infarction detected in FLAIR and DWI of a 52-year-old male patient who presented with ataxia and blurring of vision 10 h before MRI examination. Axial T1WI and T2WI were insignificant, showing no abnormalities. (a) A fairly hyper-intense lesion at the right cerebellar hemisphere was clear on T2WI, (b) the same lesion, but with a higher signal intensity was detected on DWI. DWI: diffusion-weighted MRI, FLAIR: fluid-attenuated inversion recovery; T1WI: T1-weighted imaging; T2WI: T2-weighted imaging.

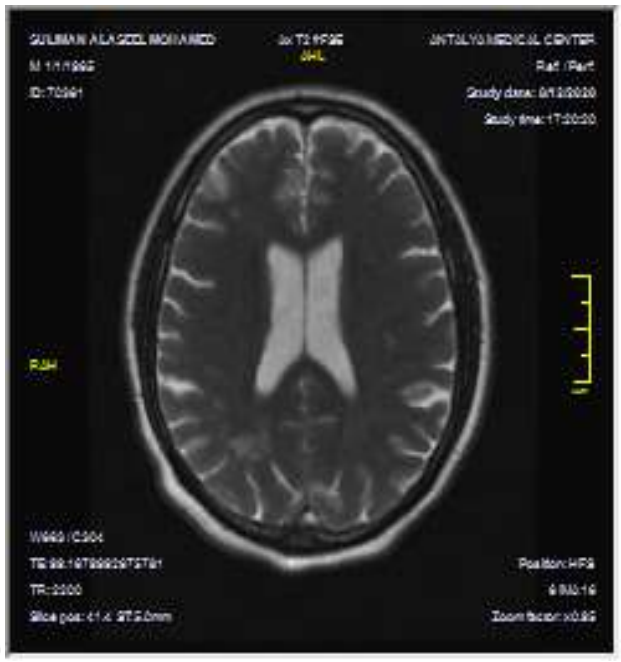
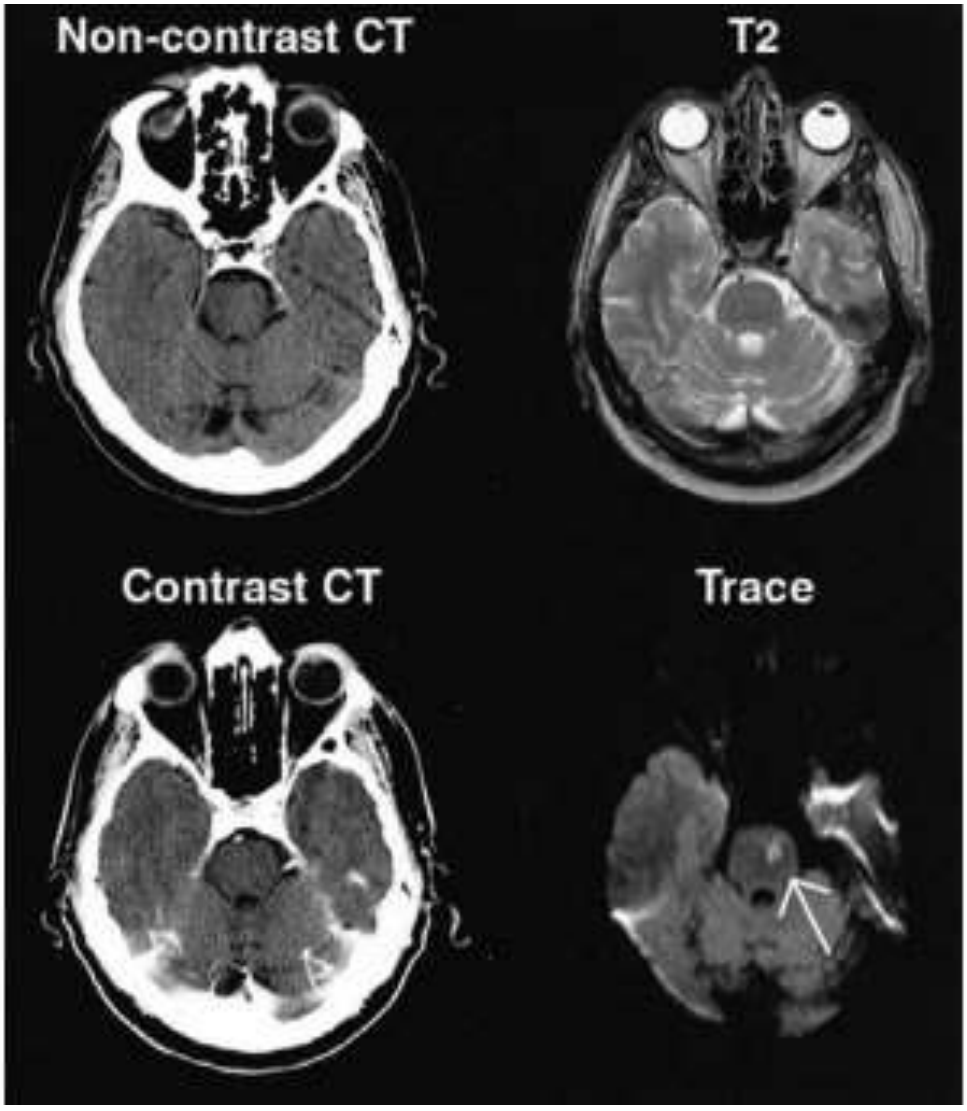
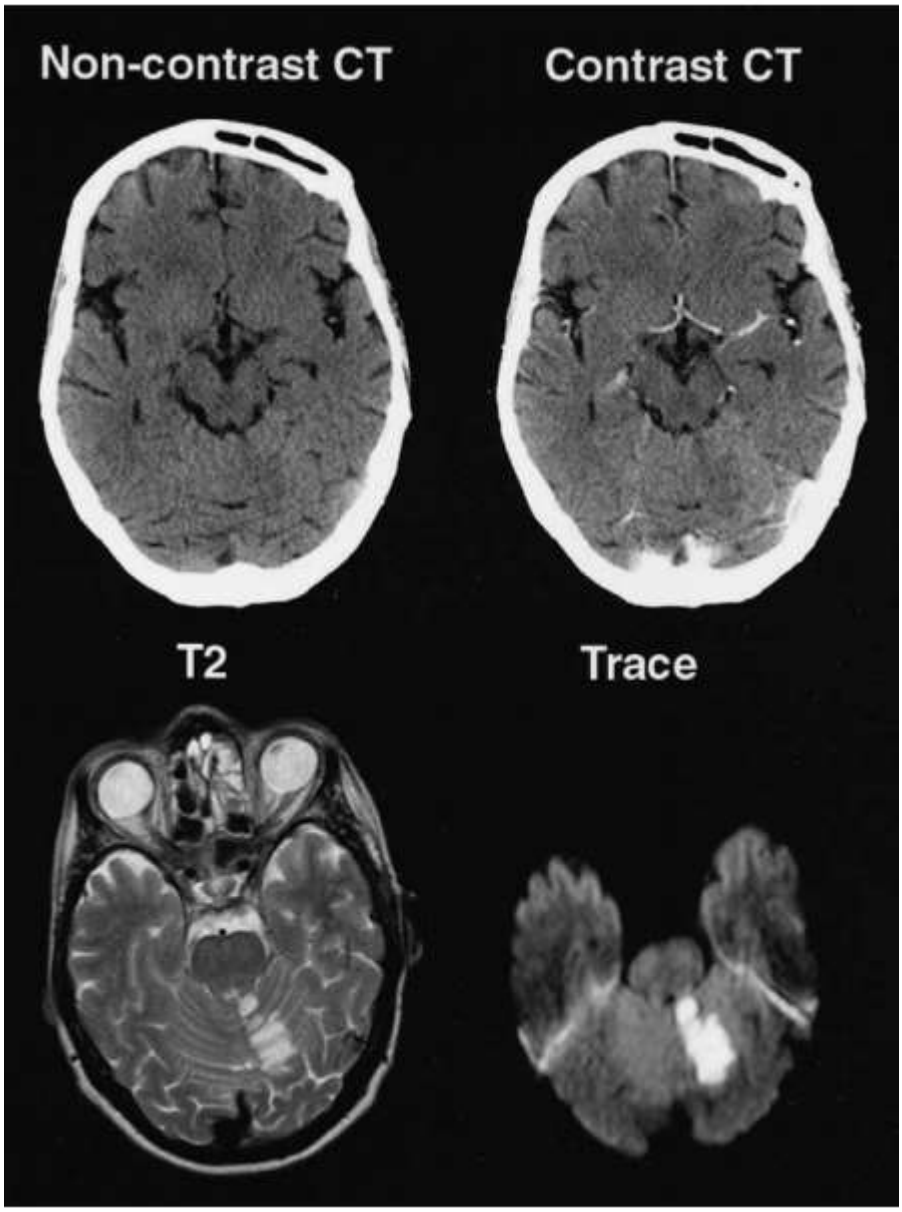
(a)  (b) 

Figure (3): **Case study 12**: Occipital lobe acute infarction detected in T2WI and FLAIR. An MR study of a 55-year-old male who presented with a sudden weakness of the left upper and lower limbs. (a) A high signal lesion on the left side of the occipital lobe is shown on FLAIR images, a less bright signal at the same site was visible on T2WI. FLAIR: fluid-attenuated inversion recovery. T2WI: T2-weighted imaging.

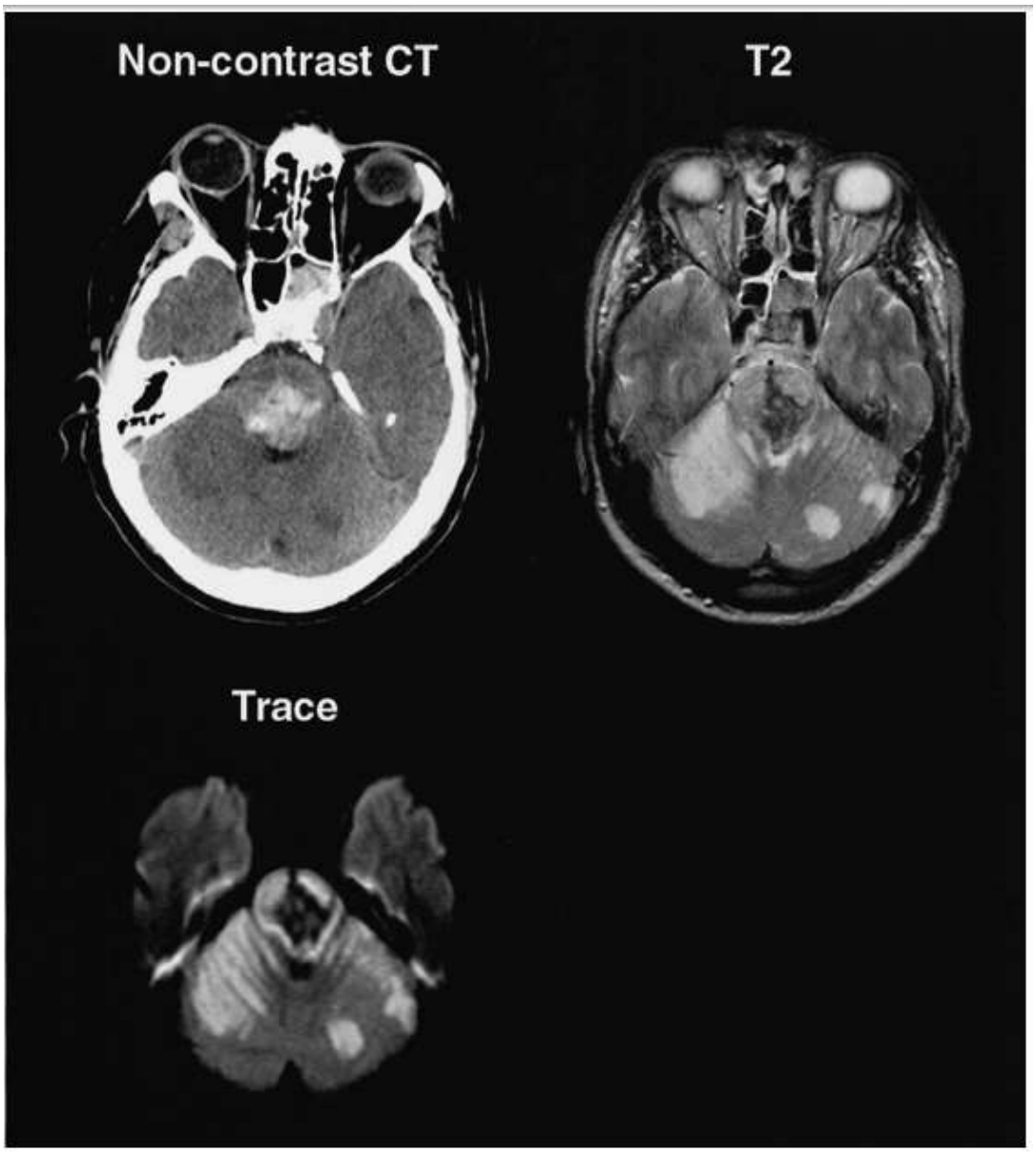
Appendices (c)
Case studies



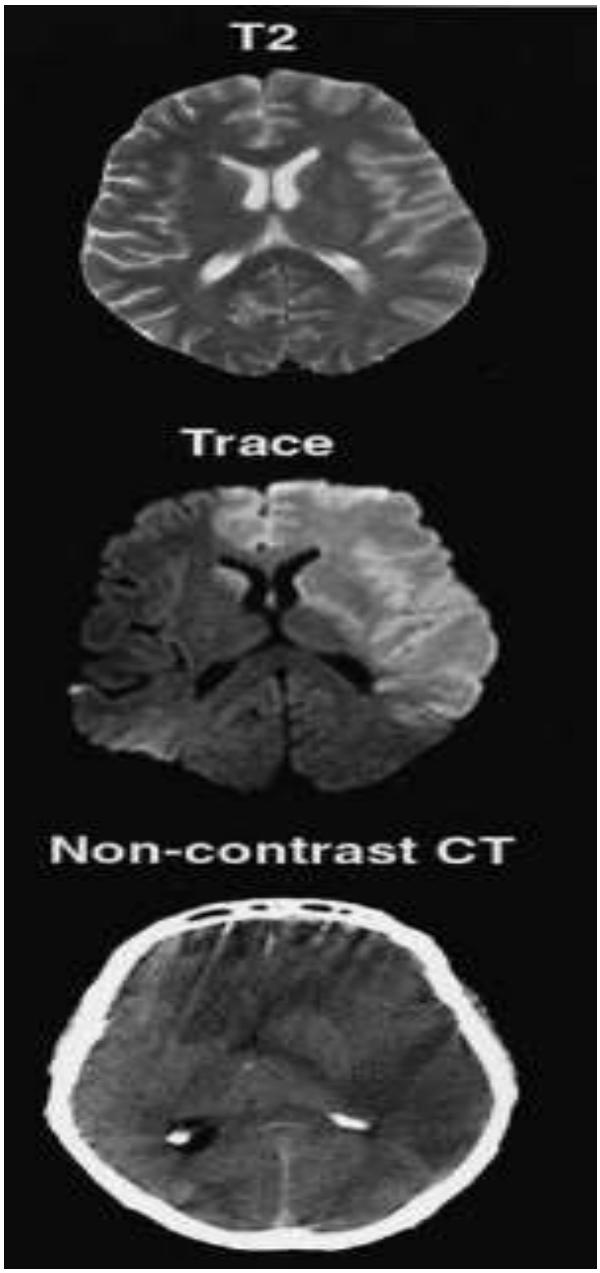
Case study 1: 65-year-old male patient showing a right arm–leg hemisyndrome with a left face palsy, allowing for the suspicion of a left pontine ischemic lesion. The MR examination obtained 6 hours after onset relates the symptomatology to an acute left paramedian pontine ischemic stroke (arrow), featuring hyperintensity on T2-weighted image and DWI trace. Even retrospectively, this stroke could not be recognized on the admission non-contrast cerebral CT obtained 4 hours after stroke onset. (Baird, A.E. and Warach, S., 1998)



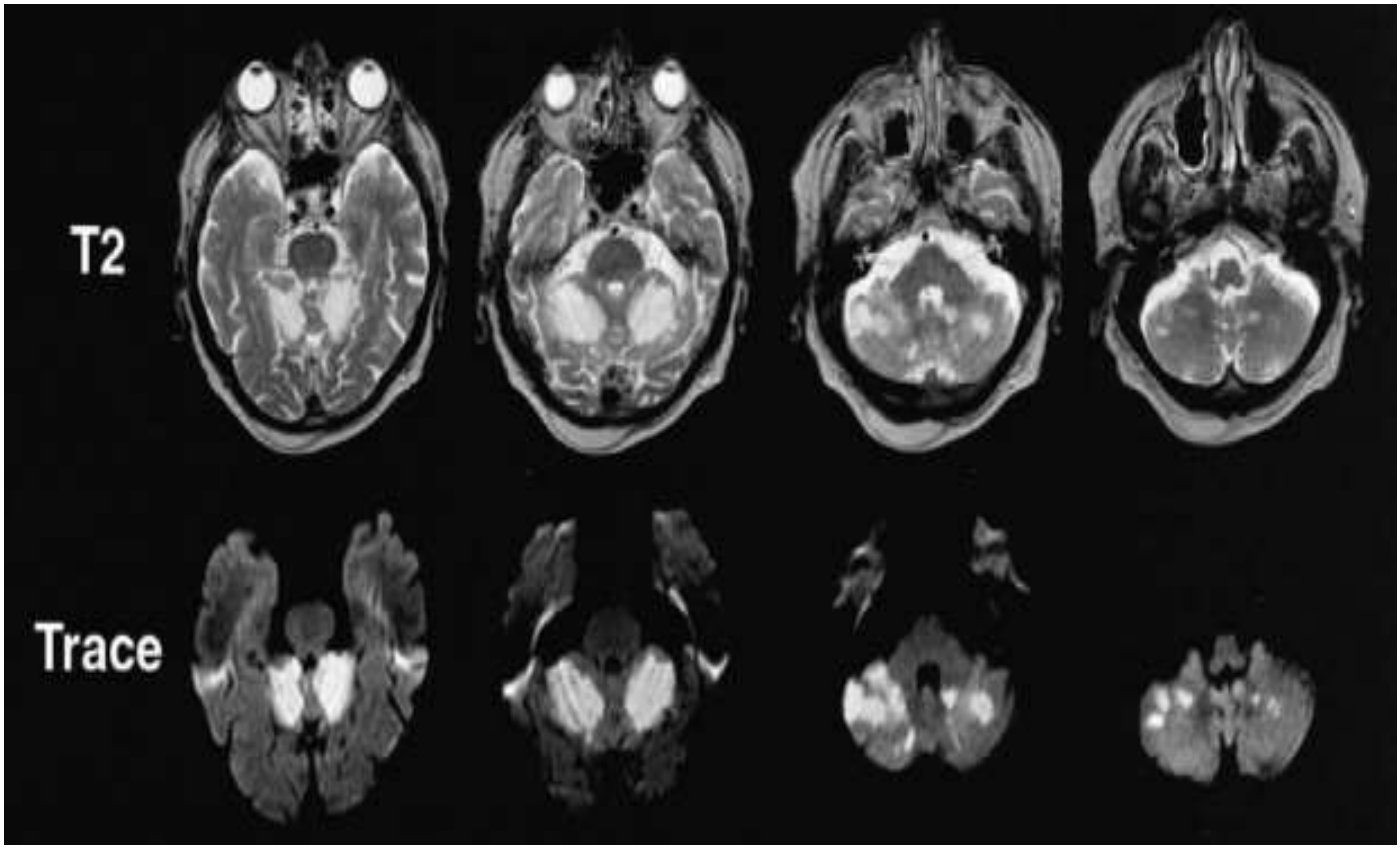
Case study 2: 58-year-old female patient admitted for headaches, nausea, vomiting, vertigo and dysarthria. Physical examination let a left cerebellar stroke be suspected. The latter was demonstrated in the territory of the left superior cerebellar artery by T2- weighted and DWI-trace obtained 24 hours after admission. On the other hand, only a slight hypodensity could be retrospectively identified in the corresponding area on the admission cerebral CT, obtained 6 hours after onset. (Baird, A.E. and Warach, S., 1998)



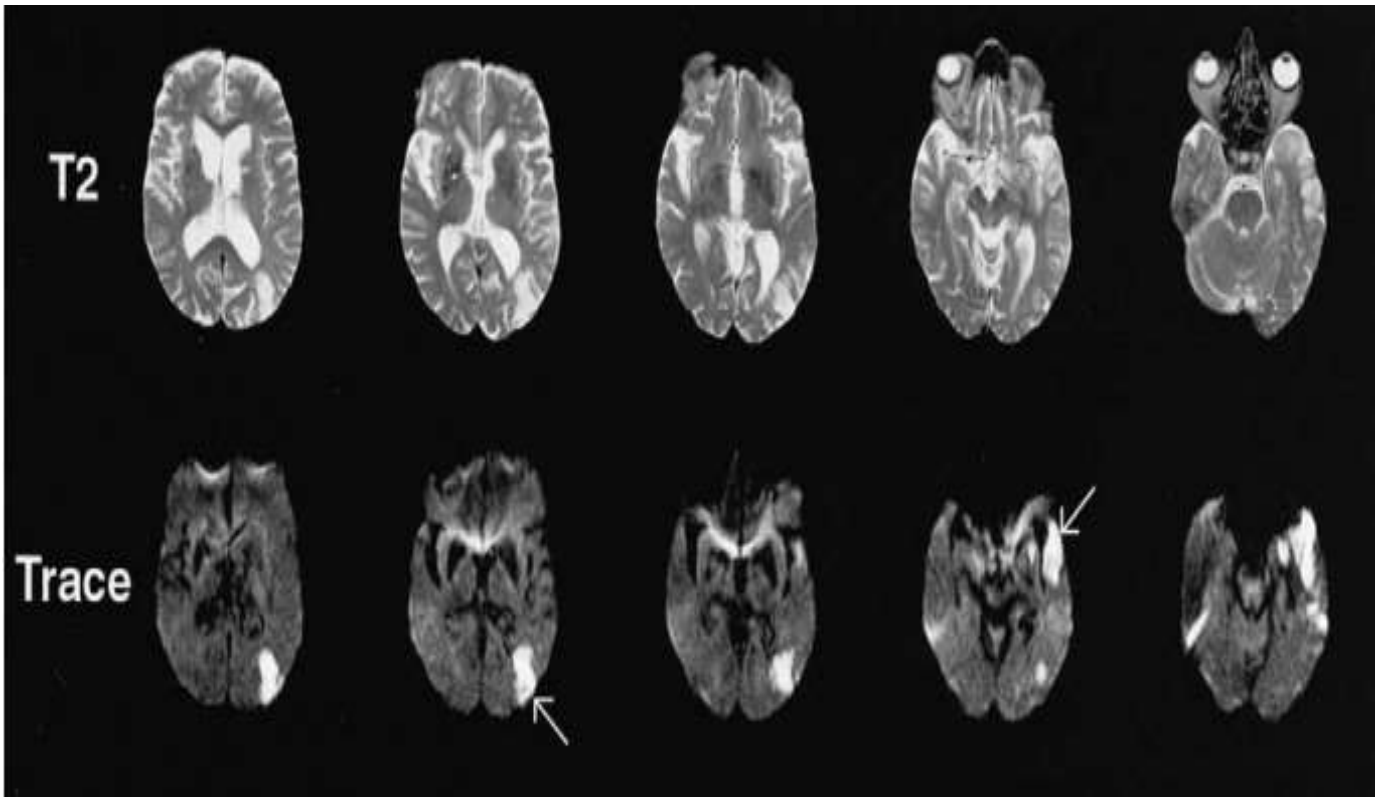
Case study 3: 48-year-old male patient admitted for thrombosis of the vertebro-basilar artery responsible for a locked-in syndrome. Intra-arterial thrombolysis was attempted without success. Post-thrombolysis CT and MR examinations demonstrate hemorrhagic transformation of a complete vertebro-basilar stroke. DWI affords precise delineation of ischemic areas in both cerebellar hemispheres as well as in the brainstem. Hemorrhagic transformation is responsible for susceptibility effects, resulting in pontine hyposignal on T2-weighted images and DWI-trace due to the T2-shine through. (Baird, A.E. and Warach, S., 1998)



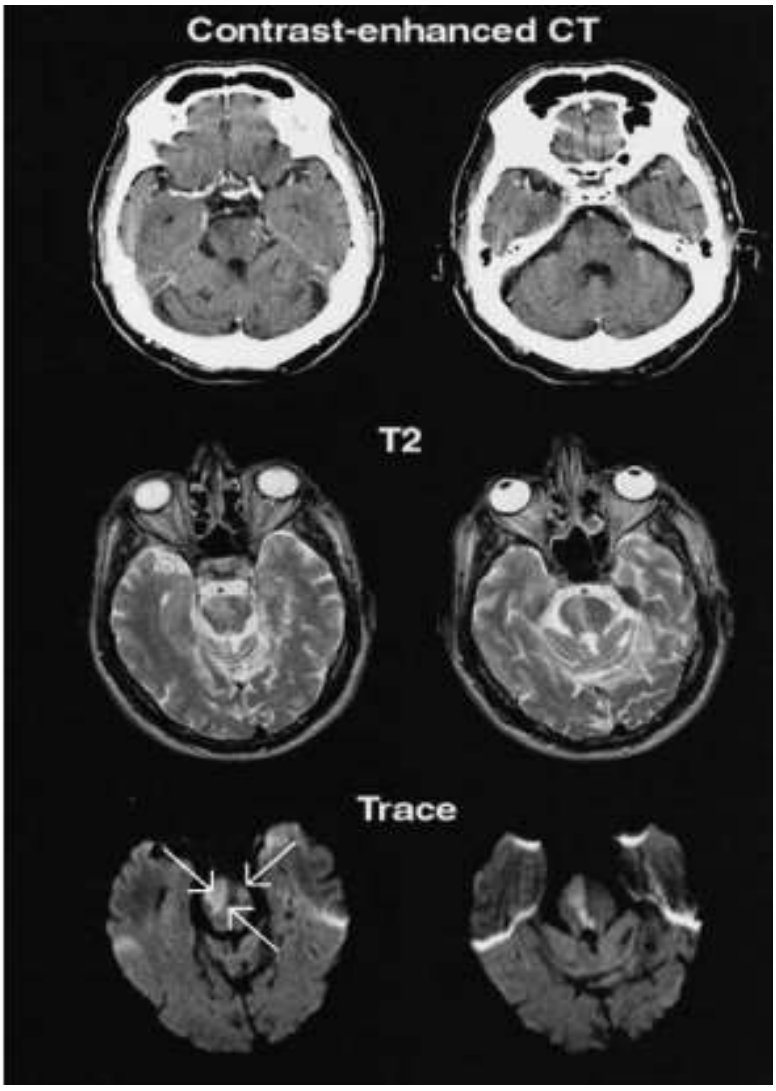
Case study 4: 52-year-old male patient found unconscious at home. Admission cerebral CT was unremarkable. The patient was transferred to our institution and a cerebral MR was performed. The latter demonstrated an extensive stroke involving both anterior cerebral artey and left sylvian artery territories. The precise stroke extent was better delineated on DWI-trace than on T2-weighted image. Follow-up cerebral CT, obtained 24 hours after cerebral MR displayed development of a malignant cerebral edema. The patient died from intracranial hypertension. (Baird, A.E. and Warach, S., 1998)



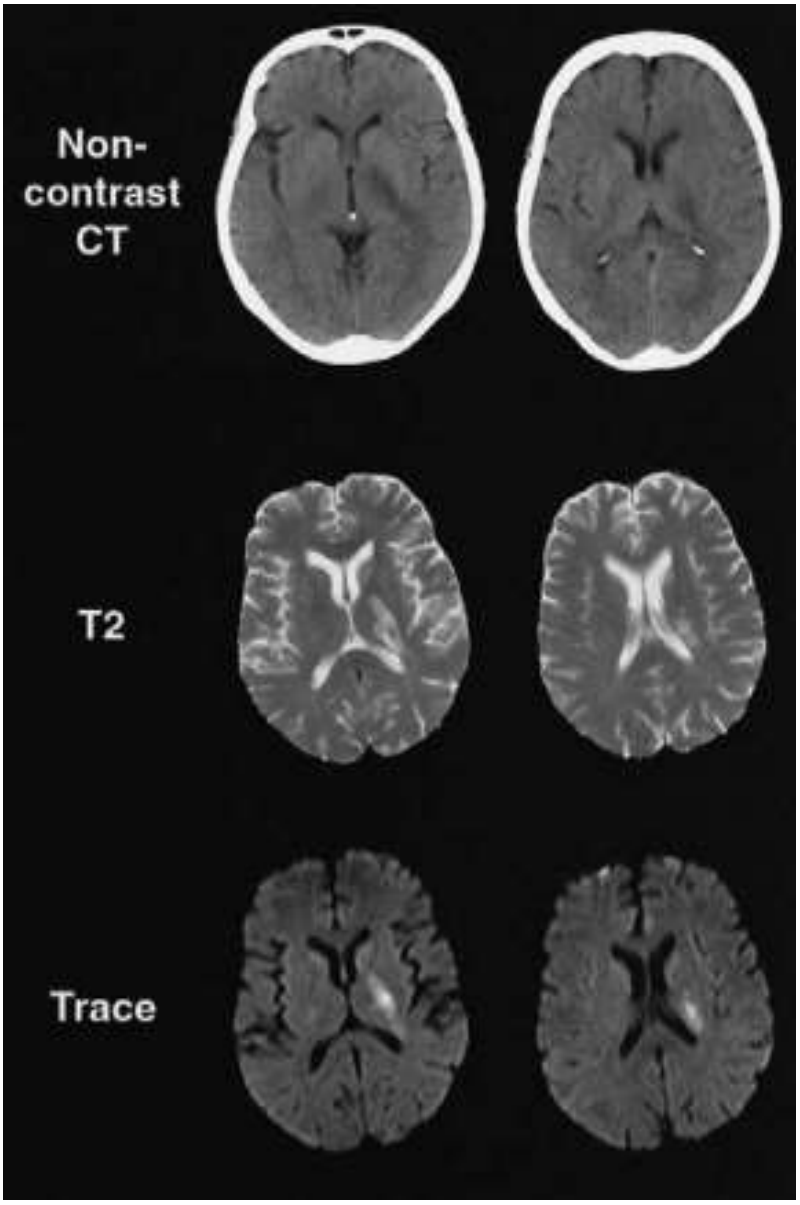
Case study 5: 72-year-old male patient admitted for violent headaches. Physical examination demonstrated severely altered cerebellous tests, as well as dysarthria and bilateral corticospinal signs. MR examination obtained 10 hours after symptomatology onset related these clinical symptoms and signs with bilateral acute strokes in the territory of superior cerebellar arteries. (Baird, A.E. and Warach, S., 1998)



Case study 6: 76-year-old male patient admitted for aphasia and visual field defect. Cerebral MR examination was obtained 4 hours after symptomatology onset. T2-weighted images show multiple focal hyperintensities (arrowheads) in both basal nuclei, as well as in external capsulae. These multiple punctual lesions have high-diffusion properties, featuring hyposignal on DWI. They relate to lacunas and dilated Virchow–Robin spaces. On the other hand, more extensive acute ischemic lesions (arrows) can be identified in the left temporal pole and in the left parieto-occipital region. They are also hyperintense on T2-weighted images, but demonstrate low diffusion properties, with hyper- and hyposignal on DWI-trace. (Baird, A.E. and Warach, S., 1998)



Caes study 7: 70-year-old male patient showing a left face–arm–leg hemisyndrome with complex oculomotricity alteration and internuclear ophthalmoplegia. Cerebral CT and MR examinations were obtained 7 and 9 hours after symptomatology onset, respectively. Cerebral MR demonstrates three ischemic lesions in the brainstem, one of them being retrospectively identified on the cerebral CT. Two of these ischemic lesions are acute. They feature hypersignal on T2- and DWI-trace, and hyposignal on the ADC maps. They are located in the right paramedian pons and mesencephalon, and in the antero-lateral portion of the left pons (arrows). On the other hand, an old lesion, also hyperintense on T2-weighted, is identified in the left central paramedian pons (arrowhead). This combination explained the patient's intricate clinical picture. (Baird, A.E. and Warach, S., 1998)



Case study 8: 70-year-old female patient admitted for a right sensitivomotor face–arm–leg hemisyndrome associated with a motor aphasia. These findings were related to a left anterior choroidial stroke both by CT and MR examinations. Noncontrast cerebral CT and T2-weighted images, as well as DWI trace, demonstrated a signal abnormality involving the posterior arm of the left internal capsula, as well as portions of the left thalamus and lentiform nucleus, adjacent to the left lateral ventricle., revealed this stroke to be actually evolving from at least 1 or 2 weeks. (Baird, A.E. and Warach, S., 1998)