STUDY ON THE TYPICAL DOSE FOR LOCAL DIAGNOSTIC REFERENCE LEVEL (DRL) IN CEREBRAL ANGIOGRAPHY FOR FEMORAL CATHETER INSERTION

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by

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Dissertation submitted in partial fulfilment of the requirements for the degree of Bachelor in Medical Radiation (Honours)

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CERTIFICATE

This is to certify that the dissertation entitled study on the typical dose for local diagnostic reference level (DRL) in cerebral angiography for femoral catheter insertion is the bona fide record of research work done by Ms Fatin Najwa binti Adnan during the period from October 2024 to June 2025 under my supervision. I have read this dissertation and that in my opinion, it confirms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfilment for the degree of Bachelor in Medical Radiation (Honours).

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated and duly acknowledged. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at Universiti Sains Malaysia or other institutions. I grant Universiti Sains Malaysia the right to use the dissertation for teaching, research and promotional purposes.

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LIST OF SYMBOLS

P_{KA}	**Kerma-Area Product**
$K_{a,r}$	**Reference Point Air Kerma**
$Gy.cm^2$	**Gray centimetres squared**
mGy	**Mili-Gray**
kV	**kilo-Volt**
mA	**Mili-Ampere**
min	**Minute**
mSv	**Mili-Sievert**
cm	**Centimetre**
µm	**Micro-metre**

LIST OF ABBREVIATIONS

DRL	Diagnostic Reference Level
LDRL	Local Diagnostic Reference Level
AK	Air Kerma
HPUSM	Hospital Pakar Universiti Sains Malaysia
ICRP	International Commission on Radiological Protection
AVM	Arteriovenous Malformation
CCF	Carotid-Cavernous Fistula
ALARA	As Low As Reasonably Achievable
DSA	Digital Substraction Angiography
IAEA	International Atomic Energy Agency
AMIEN	Advanced Minimally Invasive Endovascular & Neurointerventional
HDR	High Dynamic Range
PACS	Picture Archiving and Communication System
MMed	Master of Medicine

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KAJIAN MENGENAI DOS TIPIKAL UNTUK TAHAP RUJUKAN DIAGNOSTIK TEMPATAN (DRL) DALAM ANGIOGRAFI SEREBRUM UNTUK KEMASUKKAN KATETER FEMORAL

ABSTRAK

Pengenalan: Angiografi serebrum menggunakan kateter yang dimasukkan melalui arteri femoral dan dipandu oleh fluoroskopi untuk menggambarkan saluran darah otak yang melibatkan pendedahan radiasi yang lebih tinggi. Kajian ini bertujuan untuk mewujudkan dos tipikal untuk tahap rujukan diagnostik tempatan (DRL) untuk pemasukan kateter femoral dalam angiografi serebrum untuk meningkatkan keselamatan pesakit. **Objektif:** Kajian ini bertujuan untuk menganalisis taburan dos (P_{KA} dalam Gy.cm² dan $K_{a,r}$ dalam mGy) dengan tiga petunjuk klinikal dan kumpulan umur. Kemudian, tetapkan dos biasa dan bandingkan dos biasa dengan antarabangsa. **Kaedah:** Kajian retrospektif ini menganalisis 116 pesakit (berumur 18–78) yang menjalani angiografi serebrum di Hospital Pakar Universiti Sains Malaysia (HPUSM), Kelantan antara Januari 2020 dan Disember 2024. Data dikumpul menggunakan sistem biplane SIEMENS AXIOM-Artis Zee dan diambil daripada PACS USM. Analisis statistik telah dilakukan, dan dos biasa telah ditetapkan pada nilai median taburan dos. **Keputusan:** Produk kawasan kerma (P_{KA}) tertinggi ialah 954.08 Gy.cm² manakala yang terendah ialah 26.50 Gy.cm². Dos P_{KA} biasa ialah 270.08, 229.30, dan 251.92 Gy·cm² untuk aneurisme, kecacatan arteriovenous otak (AVM), dan fistula karotid-cavernous (CCF), masing-masing. Dos Titik Rujukan Air Kerma ($K_{a,r}$) yang sepadan ialah 1277.00, 1159.00, dan 1611.00 mGy. Nilai ini melebihi DRL kebangsaan (81 Gy·cm², 389 mGy), mungkin disebabkan oleh kes yang lebih kompleks, masa fluoroskopi yang lebih lama dan perbezaan peralatan. **Kesimpulan:** Kedua-dua P_{KA} dan $K_{a,r}$ meningkat secara berkadar dengan kV, jumlah mA, dan jumlah masa fluoroskopi. Dos biasa untuk DRL tempatan berbeza-beza berdasarkan indikasi klinikal yang berbeza. Secara keseluruhan, kajian ini menyokong usaha perlindungan sinaran dengan mempromosikan had dos yang diseragamkan dan disesuaikan secara tempatan untuk meningkatkan penjagaan pesakit dalam radiologi neurointerventional.

Kata Kunci: Angiografi serebrum, Dos biasa, Aras Rujukan Diagnostik

STUDY ON THE TYPICAL DOSE FOR LOCAL DIAGNOSTIC REFERENCE LEVEL (DRL) IN CEREBRAL ANGIOGRAPHY FOR FEMORAL CATHETER INSERTION

ABSTRACT

Introduction: Cerebral angiography uses a catheter inserted through the femoral artery and guided by fluoroscopy to visualise brain blood vessels involving higher radiation exposure. This study aims to establish typical doses for local diagnostic reference levels (DRLs) for femoral catheter insertion in cerebral angiography to improve patient safety. **Objectives:** This study aims to analyse the dose distribution (P_{KA} in Gy.cm² and $K_{a,r}$ in mGy) with three indications and age groups. Then, establish the typical dose and compare the establish typical dose with international. **Methodology:** This retrospective study analysed 116 patients (aged 18–78) who underwent cerebral angiography at Hospital Pakar Universiti Sains Malaysia (HPUSM), Kelantan between January 2020 and December 2024. Data were collected using the SIEMENS AXIOM-Artis Zee biplane system and retrieved from the PACS USM. The statistical analysis was performed, and typical dose was established at median values of dose distributions. **Results:** The highest kerma-area product (P_{KA}) was 954.08 Gy.cm² while the lowest was 26.50 Gy.cm². The typical P_{KA} doses were 270.08, 229.30, and 251.92 Gy·cm² for aneurysm, brain arteriovenous malformation (AVM), and carotid-cavernous fistula (CCF), respectively. Corresponding Reference Point Air Kerma ($K_{a,r}$) doses were 1277.00, 1159.00, and 1611.00 mGy. These values exceeded national DRLs (81 Gy·cm², 389 mGy), likely due to more complex cases, longer fluoroscopy times, and equipment differences. **Conclusion:** Both P_{KA} and $K_{a,r}$ increase proportionally with kV, total mA, and total

fluoroscopy time. Typical doses for local DRL vary based on different clinical indications. Overall, this study supports radiation protection efforts by promoting standardised, locally tailored dose limits to improve patient care in neurointerventional radiology.

Keywords: Cerebral angiography, Typical dose, Diagnostic Reference Level

CHAPTER 1

INTRODUCTION

1.1 Study Background and Rational

The International Commission on Radiological Protection (ICRP) has proposed Diagnostic Reference Levels (DRLs) as an optimisation tool in the early 1990s, and in 1997, the use of DRLs was formally introduced by European legislation (Damilakis et al., 2023). A typical dose refers to the median (50th percentile) value of a dose indicator observed during routine clinical practice for a specific procedure and patient group. In contrast, a DRL is established at the 75th percentile of the distribution of typical doses across multiple facilities, serving as a benchmark for identifying unusually high radiation doses. Both typical dose and local DRLs are important tools in the optimisation of patient radiation protection (Damilakis et al., 2023). Despite its widespread use, there is a need to standardise and monitor radiation doses to ensure they are within safe limits. In this study, typical dose and local DRLs were determined based on the 50th and 75th percentile values, respectively, of patient Kerma-Area Product (P_{KA}) and Reference Point Air Kerma ($K_{a,r}$).

Cerebral angiography is an imaging technique used to visualise the blood vessels in the brain and neck. Its main purpose is to identify abnormalities such as blockages, aneurysms, or malformations that may lead to serious conditions like strokes or haemorrhages (Moores, 2017). The procedure is performed by inserting a catheter through the femoral artery and guiding it up to the carotid artery. Local anaesthesia is administered to minimise discomfort during catheter insertion. Once the tip of the catheter reaches the target artery, an iodine-based contrast media is injected to enhance the visibility of blood vessels image at the brain. Then, X-ray images are captured as the contrast material flows through the blood vessels image in the brain. As the contrast flows through the cerebral circulation, X-ray images are captured using both frontal and lateral imaging planes. These views help visualise both intracranial and extracranial vessels from multiple angles, providing detailed anatomical information. Due to the complexity of the procedure, cerebral angiography is associated with higher radiation doses compared to standard diagnostic imaging. Therefore, in this study, the radiation dose received by patients and its associated factors are investigated.

This study focuses on three clinical indications commonly assessed using cerebral angiography which are brain aneurysm, brain arteriovenous malformation (AVM) and carotid-cavernous fistula (CCF). A brain aneurysm is a bulging or ballooning of a blood vessel in the brain caused by a weakness in the vessel wall. It may result from genetic predisposition, lifestyle factors, aging, or hypertension. If left untreated, an aneurysm can rupture potentially leading to sudden loss of consciousness, neurological damage, or even death. Brain arteriovenous malformation (AVM) is a congenital condition characterised by a tangled network of abnormal blood vessels connecting arteries and veins in the brain or spinal cord. Although AVMs are typically present at birth, many individuals remain asymptomatic until rupture occurs, which can result in intracranial haemorrhage and significant neurological complications. Meanwhile, carotid-cavernous fistula (CCF) is an abnormal connection between the carotid artery and the cavernous sinus, a venous cavity at the base of the skull can occur spontaneously or be caused by trauma such as head injuries or skull fractures, and it may present with symptoms like visual disturbances or pulsating eye symptoms.

1.2 Problem Statement

Cerebral angiography is considered as a complex diagnostic procedure in the field of angiographic imaging. Due to the complexity of the procedure, including the need for real-time fluoroscopy, multiple image acquisitions, and dual-plane imaging, cerebral angiography is associated with higher radiation doses compared to standard diagnostic imaging. Prolonged fluoroscopy time and repeated imaging sequences contribute significantly to patient exposure. According to Prajamchuea (2020), the total fluoroscopy time for cerebral angiography ranges from 1.52 minutes to 55.05 minutes, notably higher than peripheral angiography, which ranges from 0.23 minutes to 34.20 minutes. Similarly, D'Ercole et al. (2010) reported total fluoroscopy time for cerebral angiography ranging from 1 to 48 minutes. These findings highlight a concern regarding patient radiation exposure due to extended duration of the procedure. Furthermore, Soliman et al. (2021) demonstrated that the cumulative kerma area product (P_{KA}) increases by 4.16% for additional minute of fluoroscopy time, reinforcing the direct relationship between exposure time and radiation dose. These observations underscore the need for dose optimisation strategies in cerebral angiography to ensure patient safety while maintaining diagnostic quality.

Currently, there is no study that comparing DRLs in HPUSM with international DRLs for cerebral angiography procedure involving the three specified clinical indications. International DRLs often encompass a wide range of values due to differences in clinical practices and equipment used across countries. The comparison between local and international DRLs in cerebral angiography procedure highlight the importance of establishing localised standards that reflect specific clinical practices and technological capabilities. This also help in optimising radiation doses, improve patient safety, and lead to continuous improvement in the healthcare.

1.3 Research Objectives

1.3.1 General objective

This study aims to determine the typical dose for local diagnostic reference levels (DRLs)for femoral catheter insertion in cerebral angiography.

1.3.2 Specific objectives

1. To analyse dose distribution for femoral catheter insertion in cerebral angiography.
2. To establish typical dose for femoral catheter insertion in cerebral angiography.
3. To compare the established typical dose for local DRL with national and international DRLs.

1.4 Significance of Study

This study aims to analyse dose distribution of Kerma-Area Product (P_{KA}) measured in Gy.cm² and Reference Point Air Kerma ($K_{a,r}$) measured in mGy for patients undergoing cerebral angiography via femoral catheter insertion. Based on this analysis, the study will establish the typical dose associated with femoral catheter insertion in cerebral angiography. Cerebral angiography involves exposure to ionising radiation, which poses potential risks to both patients and healthcare professionals. Therefore, establishing a local DRL is crucial to ensure that radiation doses are kept as low as reasonably achievable (ALARA) without compromising diagnostic image quality. Typical dose values and DRLs serve as important benchmarks for optimising procedures and ensuring safe clinical practice in cerebral angiography procedure.

Currently, there is no study has been conducted to compare the local DRLs at Hospital Pakar USM with international standards for the three specific clinical indications. In this context, the DRL values derived from this study were compared with international DRLs. Since international DRLs tend to have broad ranges due to variability in equipment and clinical protocols, comparing local and international data emphasises the importance of establishing institution-specific reference levels. These localised DRLs reflect actual clinical practices and technological capabilities, and support more relevant and effective dose optimisation strategies.

By establishing typical dose values for femoral catheter insertion in cerebral angiography, this research contributes to standardising protocols across institutions. It provides references for evaluating whether current practices align with international recommendations, helping facilities to adjust techniques or protocols where necessary. Comparing local DRLs with international standards highlights the importance of establishing localised reference levels that accurately reflect the specific clinical practices and technological capabilities of the institution. This comparison is essential for optimising radiation doses, enhancing patient safety, and promoting continuous improvement in healthcare quality and radiation protection practices.

Regular monitoring of radiation doses against established DRLs enables continuous evaluation and improvement of imaging procedures. This ensures that deviations from best practices are identified and corrected promptly, improving both patient outcomes and procedural efficiency. As DRLs are dynamic tools, they must be periodically reviewed and updated to reflect advancements in technology and changes in clinical practice. The findings of this study provide evidence-based data that can support national or institutional authorities in developing or revising radiation safety guidelines specific to cerebral angiography. Furthermore, increased awareness of typical radiation doses and DRLs will enhance training and education for healthcare professionals performing neurointerventional procedures. By fostering a culture of safety, the study promotes better understanding of radiation risks and the importance of dose optimisation. In summary, this research is essential in improving patient safety, standardising clinical practices, and supporting the global initiative for radiation dose optimisation. It contributes to the continuous development of neurointerventional techniques and aligns with international best practice guidelines.

1.5 Scope and limitation

This study focuses on determining the typical dose for establishing a local Diagnostic Reference Level (DRL) in cerebral angiography procedures, specifically when femoral catheter insertion is used as the access method. The scope includes analysis of radiation dose metrics including kerma-area product (P_{KA}) and reference point air kerma ($K_{a,r}$) obtained during the procedure. The research is limited to adult patients (aged $\geq$ 18 years old) undergoing cerebral angiography via femoral catheter insertion at HPUSM and does not include other types of neurointerventional procedures or access routes such as radial catheterization.

Limitations include variability in patient anatomy, procedural complexity, and operator techniques, which can affect radiation dose. Data collection may also be constrained by the availability of the exam protocol or dose report. These limitations might influence the generalizability of the established DRLs, necessitating local validation and periodic updates.

1.6 Thesis organisation

This thesis is organised into five chapters. Chapter 1 introduces the research background, problem statement, research objectives, scope and limitations, as well as the significance of establishing typical dose levels for local DRLs in cerebral angiography. Chapter 2 reviews current literature on radiation dose management, DRLs in interventional neuroradiology, and relevant radiation safety standards. Chapter 3 details the methodology used to collect and analyse dose data during cerebral angiography via femoral catheter insertion. Chapter 4 presents the results of dose distributions by indications and age groups, compares them with established national and international DRLs, and discusses the implications for clinical practice and radiation protection. Finally, Chapter 5 summarizes the conclusions, highlights the contributions of this study, and suggests areas for future research to optimize patient safety during neurointerventional procedures.

CHAPTER 2

REVIEW OF LITERATURE

This chapter provides a comprehensive overview of the existing research and scholarly work related to the study's focus. This literature review critically examines previous findings, theoretical frameworks, and methodological approaches relevant to the topic, highlighting both progress and gaps in knowledge. It establishes the academic context for the research and supports the rationale for the current study by identifying how it contributes to or diverges from prior work.

2.1 Cerebral Angiography Procedure

Cerebral angiography is a specialised medical imaging technique used to visualize the blood vessels in the brain, head, and neck. It is considered the gold standard for detailed imaging of cerebral vasculature and is commonly used for diagnosis and evaluations of clinical conditions such as brain aneurysms, arteriovenous malformations (AVMs), carotid-cavernous fistulas (CCFs), and vessel blockages or stenosis that could lead to strokes or other neurological problems.

In cerebral angiography, advanced imaging technologies are used to guide the procedure and improve image quality. Fluoroscopy provides real-time dynamic X-ray imaging, allowing continuous visualisation of the catheter as it is navigated through the vascular system, ensuring precise and safe navigation to the target cerebral vessels. In many cases, a biplane imaging system is used, simultaneously acquires images from two orthogonal planes, typically anteroposterior and lateral, offering a comprehensive view of the intracranial and extracranial vasculature. To further enhance the blood vessels visibility, digital subtraction angiography (DSA) is applied. This technique involves subtracting pre-contrast images from post-contrast images to eliminate background anatomical structures such as bone and soft tissue, thereby enhancing the contrast and clarity of the cerebral blood vessels for diagnostic assessment.

2.1.1 Cerebral Angiography via Femoral Catheter Insertion

There are several vascular access options for performing cerebral angiography, including the femoral, radial, and brachial arteries. Among these, insertion via femoral artery is the most commonly utilised approach due to its reliability and anatomical advantages. Located in the groin, the femoral artery offers a large calibre and a relatively straight course to the aortic arch, facilitating smooth catheter advancement to the carotid and vertebral arteries. The selection of the access site typically depends on various factors such as the patient's vascular anatomy, clinical condition, the complexity of the procedure, and the operator's experience and preference.

Cerebral angiography via femoral catheter insertion is a widely performed, minimally invasive diagnostic procedure used to visualise the cerebral vasculature in high detail. The procedure begins with thorough patient preparation, which includes pre-procedural fasting, a review of the patient's medical history, and relevant blood tests. Once in the angiography suite, the patient is positioned supine, and the groin area is sterilised. Under local anaesthesia, the right common femoral artery is punctured using the Seldinger technique (Dowd, 2020). A guidewire is introduced through the needle, the catheter is then navigated through the arterial system under fluoroscopic guidance to reach the cerebral circulation, such as the internal carotid or vertebral arteries. Once the catheter is accurately positioned, iodinated contrast media is administered to enhance visibility of cerebral vasculature. Digital subtraction angiography (DSA) is then performed to obtain high-resolution images of the cerebral vessels by digitally subtracting overlying bone and soft tissue structures from the images. This imaging technique allows detailed evaluation of cerebral hemodynamic and the identification of vascular abnormalities such as aneurysms, arteriovenous fistula, and arteriovenous malformations.

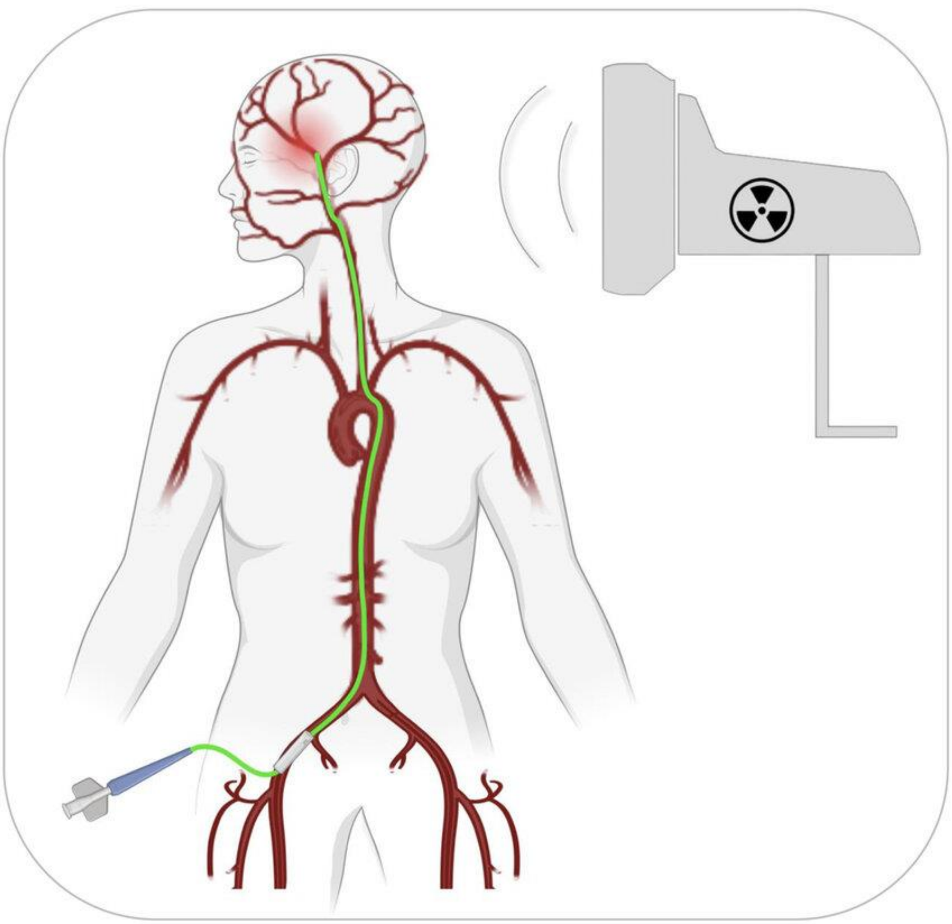

Figure 2.1 The figure shows the illustration of cerebral angiography procedure via femoral catheter insertion (Chen et al., 2023).

After imaging, the catheter is carefully withdrawn, and manual compression is applied to the femoral puncture site to prevent bleeding. Patients are monitored for potential complications, which are rare but can include groin hematoma, femoral artery thrombosis, vessel dissection, or neurological events such as stroke (Gupta & Saba, 2022). The femoral approach is preferred due to its efficiency in accessing multiple cerebral vessels and its ability to perform selective and sub-selective catheterisations. This route enables rapid and comprehensive evaluation of both internal carotid arteries and vertebral arteries within a relatively short time frame, making it particularly advantageous in diagnostic and interventional neurovascular procedures. Although it may require more equipment and prolonged fluoroscopy time compared to other approaches, the femoral approach remains the standard method due to its reliability, versatility, and comprehensive vascular access (Shin et al., 2013). The use of proper techniques, including careful catheter flushing to prevent thromboembolic complications, and the application of roadmap imaging, further enhances procedural safety and effectiveness. As a result, cerebral angiography via femoral catheter insertion continues to be regarded as the gold standard for the diagnosis and treatment of cerebrovascular disorders (Gupta & Saba, 2022).

After the procedure, the patient was required to rest the right lower limb (the catheter insertion site) for about six hours to prevent bleeding. Medical staff must closely monitor for complications such as bleeding at the puncture site or delayed post-procedural effects, including those related to contrast use or radiation exposure. The entire procedure, including patient preparation, catheterisation, image acquisition, and post-procedural recovery, typically takes one to three hours (Shin et al., 2013). Due to the complexity of the procedure, including the need for real-time fluoroscopy, multiple image acquisitions, and dual-plane imaging, cerebral angiography is associated with higher radiation doses compared to standard diagnostic imaging. Prolonged fluoroscopy time and repeated image sequences contribute significantly to patient exposure.

2.1.2 Clinical Indications for Femoral Catheter Insertion in Cerebral Angiography

Femoral catheter insertion for cerebral angiography is commonly indicated for variety of diagnostic and therapeutic neurovascular procedures. This approach enables detailed visualisation of the cerebral vasculature and is essential for the evaluation and management of several critical conditions such as brain (or intracranial) aneurysms, arteriovenous malformations (AVMs), arteriovenous fistulas (AVFs), carotid-cavernous fistulas (CCFs), ischemic stroke or transient ischemic attack (TIA), cerebral vasculitis, and other inflammatory conditions. However, this study focuses specifically on the three most encountered clinical indications for cerebral angiography using the femoral catheter insertion approach at Hospital Pakar USM (HPUSM). These include brain aneurysms, arteriovenous malformations (AVMs), and carotid-cavernous fistula (CCFs). These conditions represent the majority of neurovascular cases referred for cerebral angiography at HPUSM.

A brain aneurysm is a pathological bulging or dilation of a cerebral artery, typically occurring at arterial branching points where hemodynamic stress is greatest, most commonly found in the Circle of Willis at the base of the brain (Wang & Huang, 2024). It results from localised weakness in the arterial wall, where sustained blood flow and intraluminal pressure cause the vessel to bulge outward and form an aneurysmal sac. The majority of brain aneurysms are saccular (berry) aneurysms, characterised by a rounded in shape, saclike outpouching (Figure 2.2). Many aneurysms remain asymptomatic and undetected, unless they enlarge sufficiently to compress adjacent neural structures or rupture (Daskalov et al., 2025). Aneurysm rupture leads to subarachnoid haemorrhage (SAH), which is bleeding in the brain, , which is a severe and potentially fatal form of haemorrhagic stroke (Wang & Huang, 2024).

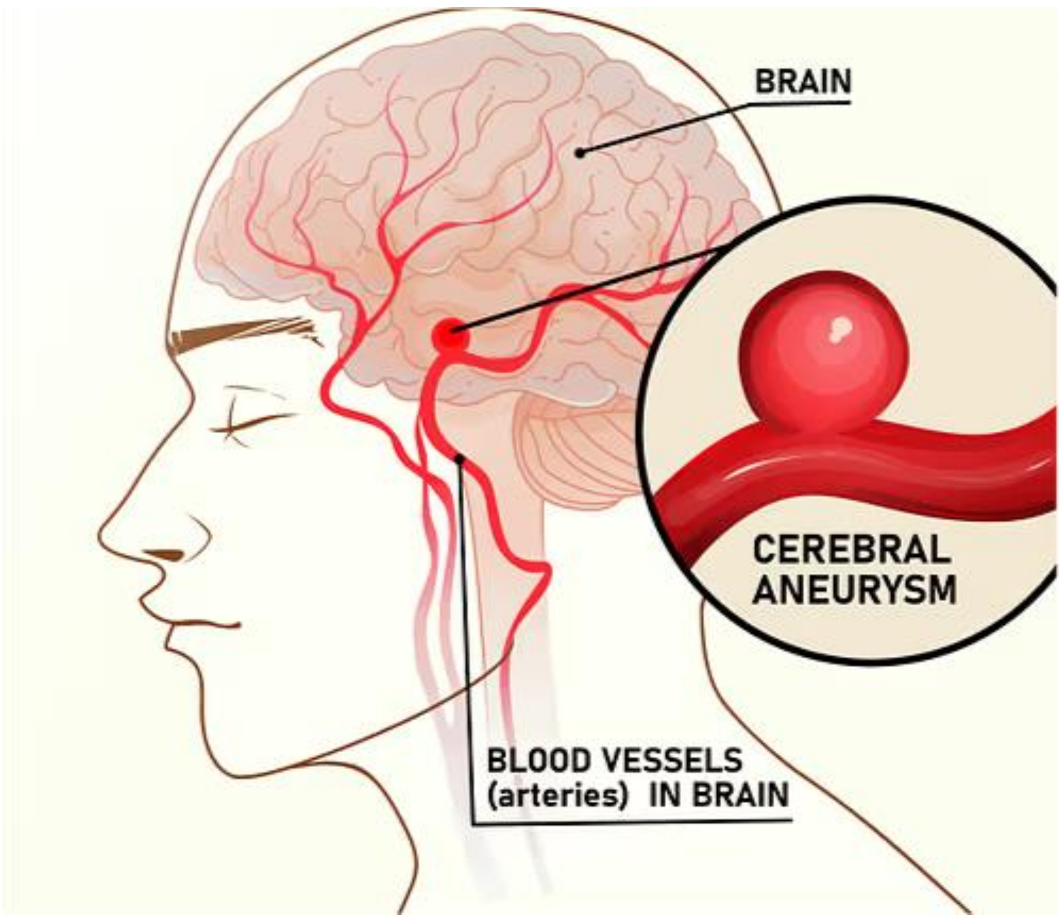

Figure 2.2 The figure shows brain aneurysm condition where there is a bulging in the blood vessel located in the brain (Lobo, 2024).

Brain arteriovenous malformations (AVMs) are rare but potentially life-threatening congenital vascular anomalies characterised by an abnormal, tangled network of dysplastic arteries and veins that connect blood directly without the presence of an intervening capillary bed (Figure 2.3). This direct arteriovenous connection results in high-pressure arterial blood flowing into low-resistance venous structures, significantly increasing the risk of rupture and intracerebral or subarachnoid haemorrhage. Haemorrhagic presentation is a leading cause of morbidity and mortality, particularly among younger individuals. In addition to rupture, AVMs may present with seizures, headaches, or other neurological symptoms due to the "steal phenomenon", where blood is diverted from the surrounding normal brain tissue, resulting in local cerebral ischemia (Jabarkheel et al., 2024).

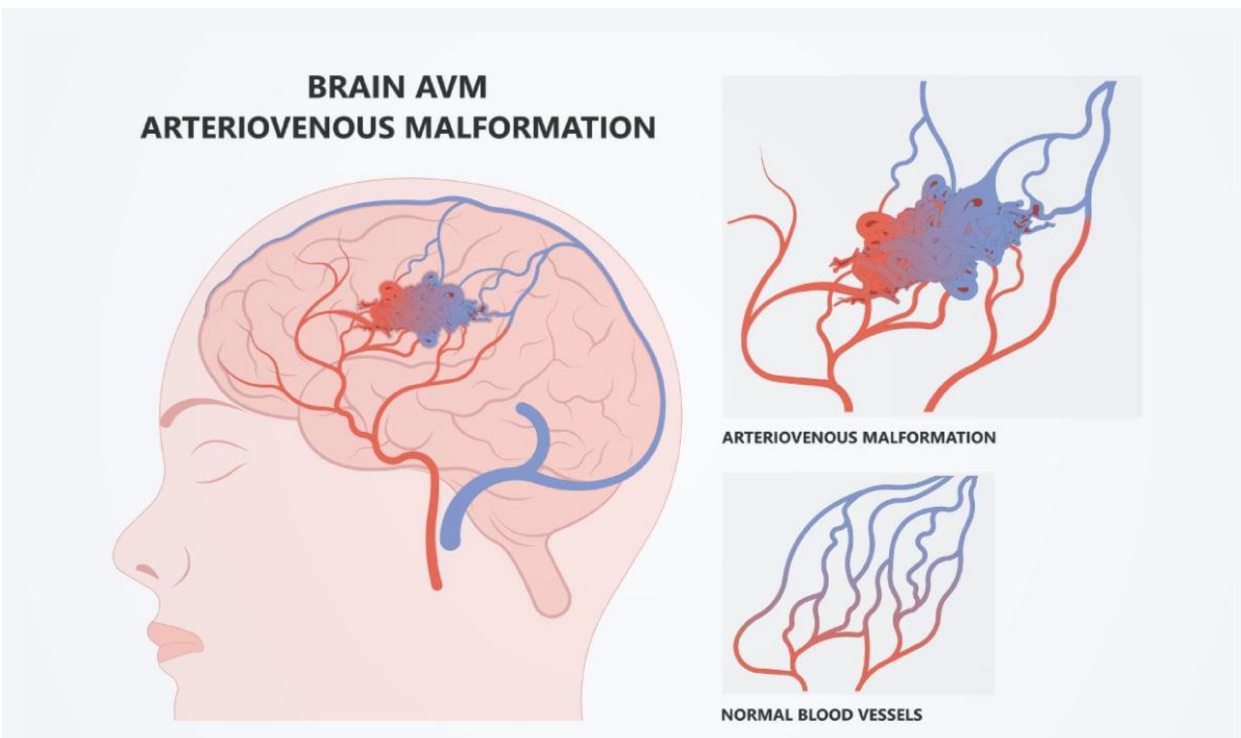

Figure 2.3 The figure shows brain arteriovenous malformation condition where there is an abnormal and tangled capillaries network (Itthimathin, 2024).

Carotid-cavernous fistula (CCF) is an abnormal vascular connection between the carotid artery (internal or external) and the cavernous sinus, classified into four types (A-D) based on arterial supply and hemodynamics, with type A being direct high-flow fistulas typically post-traumatic and types B-D being indirect low-flow fistulas often spontaneous (Gele et al., 2025). Traumatic CCFs, accounting for the majority of cases, result from head trauma such as skull base fractures, while spontaneous CCFs may arise from ruptured cavernous aneurysms or connective tissue disorders like Ehlers-Danlos syndrome (Yang et al., 2025). Patients commonly present with ophthalmic symptoms including proptosis, chemosis, diplopia, visual impairment, and orbital bruit due to venous congestion and increased intraocular pressure (Gele et al., 2025). Diagnosis relies on imaging, with MRI and CT showing characteristic signs like superior ophthalmic vein dilation and cavernous sinus enlargement, but digital subtraction angiography (DSA) remains the gold standard for confirmation and treatment planning (Alatzides et al., 2023).

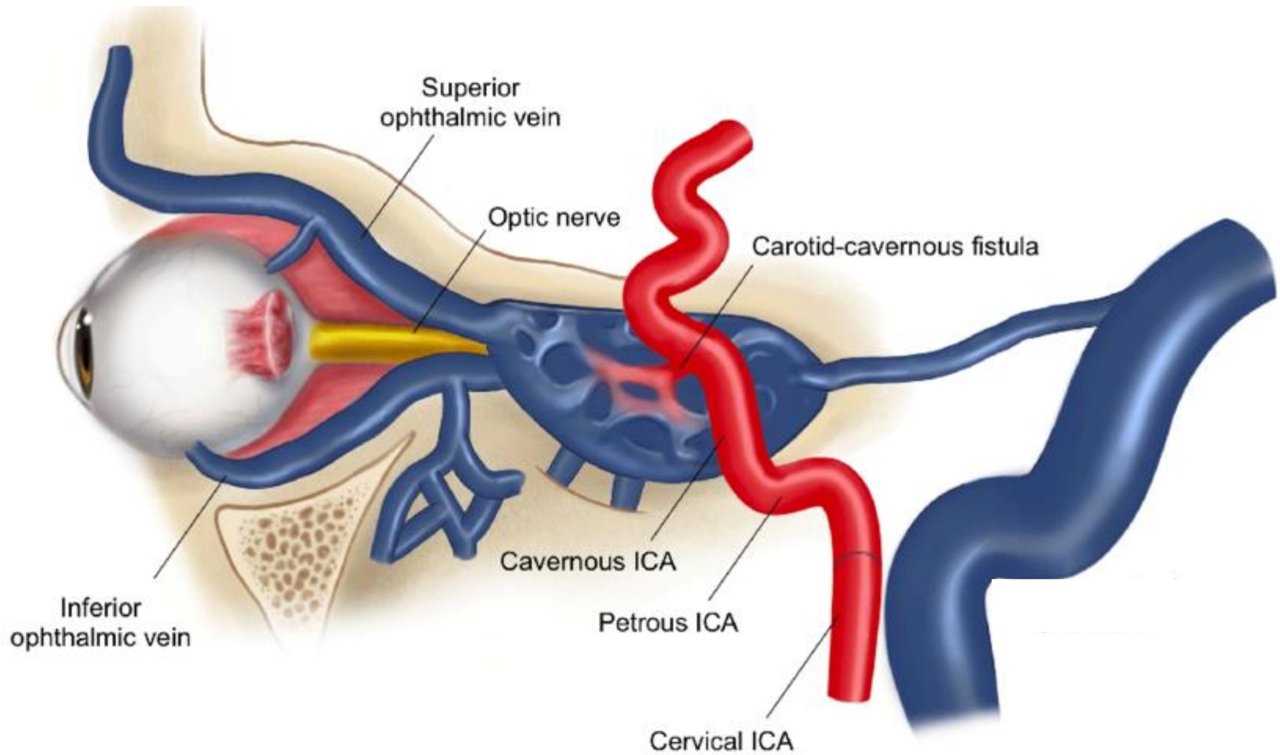

Figure 2.4 The figure shows the anatomical illustration of carotid-cavernous fistula (CCF) (Al-shalchy et al., 2024).

2.2 Radiation Dose in Angiography

Radiation dose in cerebral angiography is a critical concern due to the potential risks associated with ionising radiation exposure to patients and healthcare professionals, particularly to radiosensitive organs such as the eye lens. Prolonged or repeated exposure can increase the likelihood of deterministic effects, including radiation-induced cataracts. Recent advancements in dose-reduction strategies have demonstrated significant benefits in minimising patient and staff exposure without compromising diagnostic quality. For instance, the implementation of wedge filters has been shown to reduce radiation dose to the eye lens by approximately 47% while preserving image quality (Eo et al., 2025). Furthermore, the use of advanced filtration methods, such as copper filters, have resulted in reduction of the kerma-area product (P_{KA}) by approximately 40–55%, thereby effectively lowering the total patient's radiation dose received during diagnostic cerebral angiography (Kim et al., 2017). These technological enhancements are essential for minimising deterministic effects like radiation-induced cataracts while maintaining diagnostic efficacy.

In addition to patient safety, occupational radiation exposure to healthcare professionals involved in interventional neuroradiology procedures is a significant concern as they are at higher risk of radiation exposure (James et al., 2014). Prolonged exposure, particularly without adequate protection, can pose long-term health risks. A study by Somtom et al., (2022) assessing operator exposure and radiation doses during cerebral angioplasty procedures reported a maximum dose of 0.29 mSv to the left eye lens and 0.24 mSv to the left leg in the absence of protective shielding. These findings underscore the importance of implementing protective measures, including the use of lead aprons, thyroid shields, and lead glasses to mitigate exposure. Furthermore, real-time dose monitoring and adherence to dose-reduction protocols are essential to uphold the ALARA (As Low As Reasonably Achievable) principle, ensuring the safety of both patients and medical personnel during cerebral angiography.

2.2.1 Radiation Dose Quantity

Cerebral angiography involves exposure to ionising radiation, making accurate dose assessment essential for ensuring patient safety and optimising imaging protocols. Two primary dose quantities commonly used to evaluate patient radiation exposure in this procedure are the Kerma-Area Product (P_{KA}) and the Reference Point Air Kerma ($K_{a,r}$). These metrices provide complementary information on the total radiation energy delivered and the dose at a defined reference point, respectively. Both quantities are essential for assessing radiation risk, comparing dose levels across procedures, and establishing diagnostic reference levels (DRLs) to support dose optimisation strategies.

The kerma-area product (P_{KA}), measured in Gy·cm², quantifies the total radiation energy delivered during cerebral angiography by multiplying the air kerma (radiation energy absorbed per unit mass) with the irradiated area (Sanchez et al., 2014). It serves as an essential parameter for assessing patient radiation exposure and optimising safety in neurointerventional procedures (Sarma et al., 2024). P_{KA} provides a comprehensive measure of the total radiation energy delivered to the patient, accounting for both the intensity of the X-ray beam and the size of the irradiated field. Recent studies have emphasised the importance of P_{KA} in monitoring and optimising radiation doses in neurointerventional procedures, as it shows a strong correlation with patient skin dose and overall radiation risk. For instance, a recent study involving over 2,000 cerebral angiography procedures reported median P_{KA} values of approximately 120 Gy·cm² employing newer angiography systems, representing nearly a 50% reduction compared to older systems. This finding highlights the role of technological advancements in significantly reducing patient radiation exposure without compromising diagnostic efficacy (Li et al., 2024).

Reference point air kerma ($K_{a,r}$), measured in milligray (mGy), quantifies the cumulative radiation dose delivered to a standardised reference point, typically located 15 cm from the isocentre toward X-ray tube focal spot, during cerebral angiography (Figure

2.5). This metric is essential for assessing patient exposure to ionising radiation, particularly in relation to deterministic effects, such as radiation-induced skin injury, which may occur at dose thresholds exceeding 2,000 mGy (Assimos & Canevaro, 2024). As such, $K_{a,r}$ serves as a key indicator for monitoring and minimising the risk of localised tissue damage in high dose neurointerventional procedures.

Modern angiography systems display $K_{a,r}$ in real-time, enabling operators to monitor and adjust protocols to meet the safety standards. Recent studies highlight median $K_{a,r}$ values of 1,112 mGy for diagnostic cerebral angiography and 2,420 mGy for therapeutic neurointerventional procedures (e.g., aneurysm embolization), reflecting the increased complexity and fluoroscopy time required for interventions (Hitomi et al., 2019). Advanced techniques, such as high kilovoltage (kV) protocols and reduced frame rates, have reduced $K_{a,r}$ by up to 50% in newer angiography systems compared to older models. This demonstrating the impact of technological advancements on dose optimisation (Kirisattayakul et al., 2023).

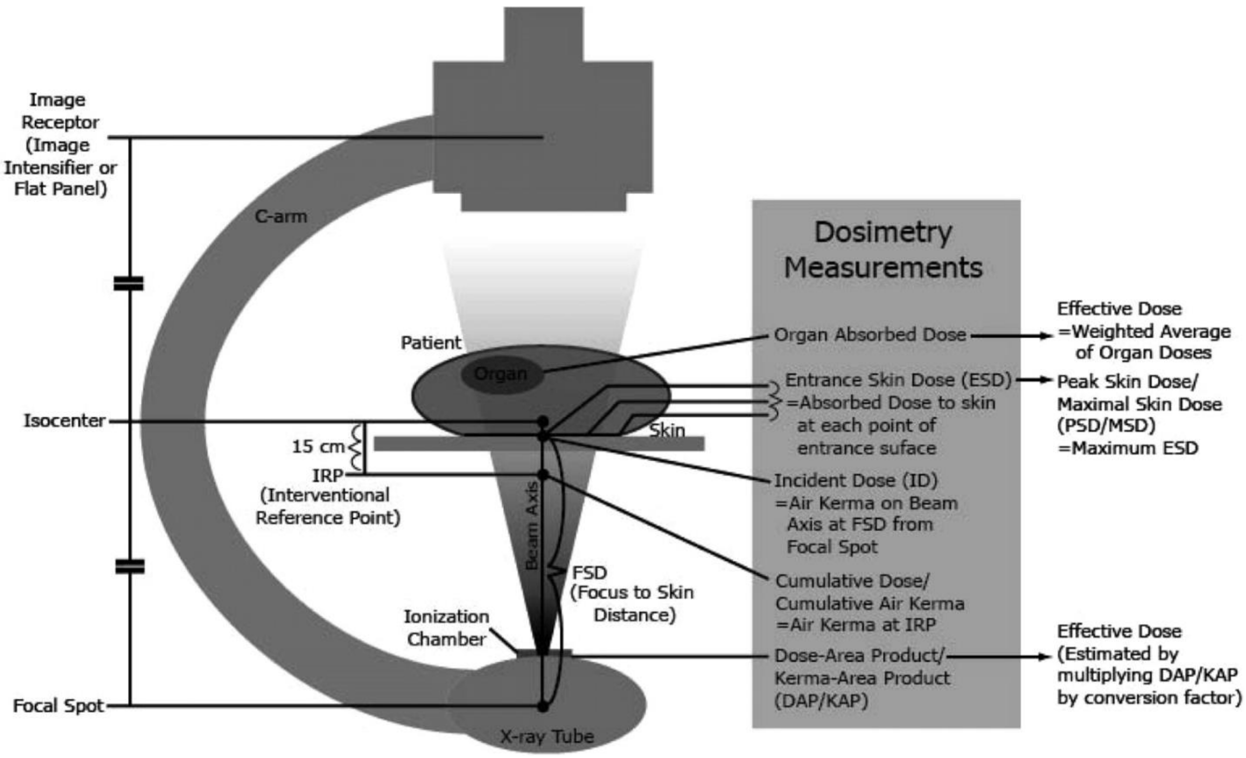

Figure 2.5 The figure shows the illustration of the reference point air kerma measured typically 15 cm from the X-ray source (Einstein et al., 2007).

2.2.2 Factors Associated with Angiography Dose

Radiation dose in cerebral angiography is influenced by combination of patient- and procedure-related factors, including patient age, anatomy complexity, clinical indication, procedure complexity, and imaging protocols employed. Additionally, Zurihanaz and Noor (2023) reported that multiple variables, such as patient-specific characteristics, equipment configuration, procedural complexity, the operator's proficiency with the imaging system, and the interventional radiologist's level of experience, can significantly influence Diagnostic Reference Level (DRL) values. These factors contribute to variability in radiation dose outcomes. A comprehensive understanding of these determinants is critical for effective dose optimisation, enhancing procedural efficiency, and ensuring patient safety. Therefore, in this study, the relationship between patient age groups and radiation dose, specifically Kerma-Area Product (P_{KA}) and Reference Point Air Kerma ($K_{a,r}$), were investigated.

One of the key factors that influencing radiation dose is patient age, which has been shown to correlate positively with fluoroscopy time. As reported by Song et al. (2020), a positive correlation between patient age and fluoroscopy time was observed (Figure 2.6). Similar findings were also reported by Opitz et al., (2022), who observed that both kerma area product (P_{KA}) and fluoroscopy time increased significantly with advancing patient age. This increament is attributed to the greater vascular tortuosity while commonly observed in older patients, and frequently linked to the greater complexity of treatment, which impacts radiation exposure in elderly patients. Increased patient age is associated with prolonged fluoroscopy durations, primarily due to age-related vascular tortuosity that complicates catheter navigation during cerebral angiography. The complexity of manoeuvring through tortuous vessels in older patients requires longer fluoroscopy times, thereby increasing radiation exposure. More complex catheter navigation through tortuous vessels can prolong the procedure, thereby increasing radiation exposure.

Figure 4.6 shows a positive correlation between age and fluoroscopy time that represent as the linear line pointing upward. Based on Song et al. study, the implementation of a dose reduction strategy revealed that patients under 50 years of age had an average fluoroscopy time of 5.8 minutes, compared to 9.5 minutes in patients over 50 years. This indicates the significant influence of age on both procedural complexity and radiation dose. In a subgroup analysis of patients aged over 60 years, both the mean fluoroscopic time and radiation dose were significantly higher compared to those aged under 60 years. Specifically, the mean fluoroscopy time increased from 7.9 minutes to 12.4 minutes, and the mean dose increased from 3.87 Gy·cm² to 5.73 Gy·cm², representing approximately a 50% increase in both parameters. Additionally, the fluoroscopy component contributed a greater proportion of the total radiation dose, 23% in the routine-dose group and 11% in the low-dose group, compared to 14% and 7%, respectively in younger patients.

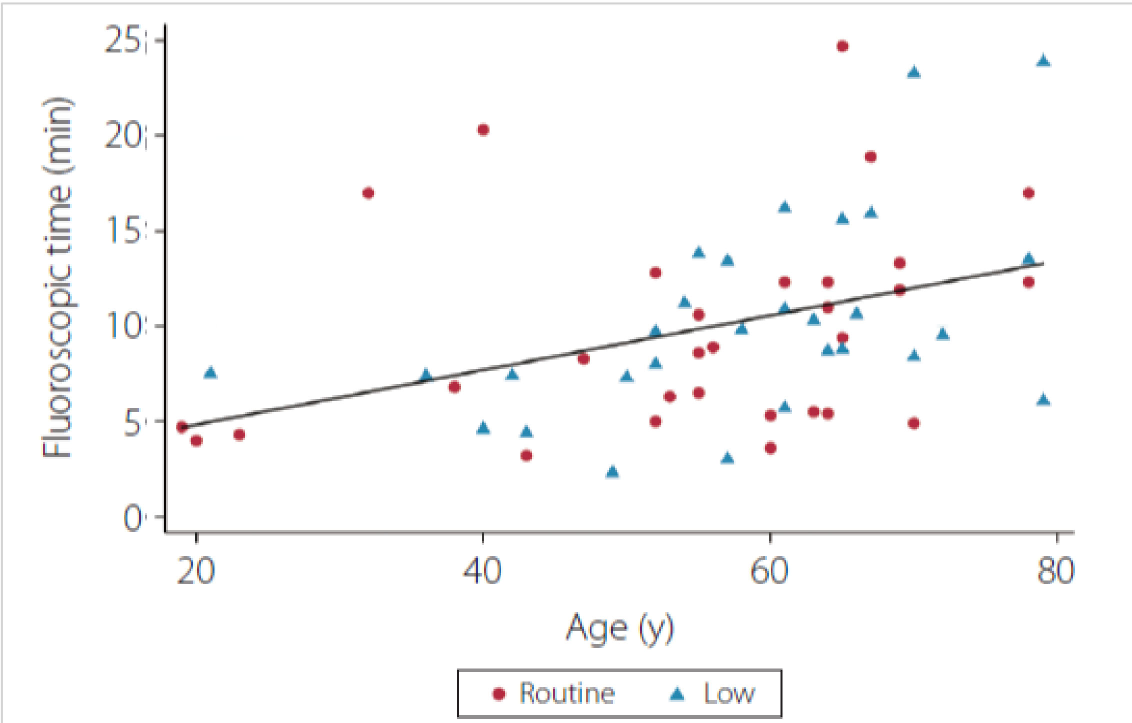

Figure 2.6 The scatter plot of the fluoroscopic time and age of the patients. The red circle indicates the routine group (n=30), and the blue triangle indicates the low dose group (n=30). The solid line is the linear regression line for the entire group (Song et al., 2020).

As patients age getting older, increased vascular tortuosity often requires longer fluoroscopy times to safely and effectively navigate the catheter through the blood vessels. This extended manipulation contributes to higher total radiation doses received by the patient.

These findings highlight the increased procedural complexity and radiation exposure associated with elderly patients. Therefore, tailored dose optimisation strategies, particularly the implementation of low-dose imaging protocols, are crucial for elderly patients, who are more susceptible to increased radiation burden due to anatomical changes associated with aging.

2.3 Local Diagnostic Reference Level (LDRL)

Local Diagnostic Reference Levels (LDRLs) are institution-specific benchmarks used to monitor and optimise radiation doses during diagnostic imaging procedures (Moore, 2024). Unlike national DRLs, which provide general dose thresholds based on broad population data, LDRLs are tailored to the actual practice and equipment of a particular institution. They serve as effective tools to identify abnormally high or low radiation doses, which may lead to reassessment and possible modification of imaging techniques to ensure that doses are kept as low as reasonably achievable without reducing the quality of diagnostic images (Damilakis et al., 2023).

Recent studies emphasize the importance of establishing size-dependent and scanner-specific LDRLs, recognising that patient size significantly influences the radiation dose required for adequate imaging (Boere et al., 2018). This approach helps differentiate between acceptable dose variations due to patient size and true outliers that may indicate unnecessarily high exposure or compromised image quality (Alrehily et al., 2023).

The process of establishing LDRLs involves collecting dose metrics from a representative sample of procedures. The commonly used dose indicators in cerebral angiography are kerma-area product (P_{KA}) and reference point air kerma ($K_{a,r}$). According to the International Commission on Radiological Protection (ICRP), the 75th percentile (third quartile) of the collected dose distribution is typically used to set the DRL for a given procedure (Ihn et al., 2021).

The typical dose value for interventional procedure is defined based on the median (50th percentile) of the DRLs value (Zurihanaz and Noor, 2023). A typical dose value of local DRLs assist in dose management of interventional procedures which considering the stochastic effects (Prajamchuea, 2020). It should be set for each examination or procedure for each clinical indication to easily trace any uncommon practices (Zurihanaz and Noor, 2023). If the values of median of local DRLs are higher than 75th percentile of national DRLs, the investigation should be done with problem evaluation, the protocols of procedure, and the exposure techniques or settings (Prajamchuea, 2020).

The DRLs value are the indicator used to identify the dose to the patient is unusually high or low in a specified radiological procedure for medical imaging equipment (IAEA, 2017). DRLs were determined through the 75th percentile of the dose distribution and act as a guide for monitoring dose to individual patients (Zurihanaz and Noor, 2023). Therefore, DRL is not a dose limit, but as a tool for dose optimisation during diagnostic procedures (Erskine et al., 2014). The ICRP indicates that DRLs are recommended for health professional and organisations to measure the dose distribution among patients and for local review if regularly exceeded. They recommended considering DRLs as much as possible during all procedures using radiation because the cumulative fluoroscopy exposure time is a poor metric of patient radiation dose (Hayashi et al., 2022). Besides, DRLs are required to