

“Effectiveness of Low-Dose Protocols in Cerebral Digital Subtraction Angiography: A Study on Radiation Dose Reduction and Image Quality Assessment”

Dr. Mahendra Kumar Verma¹, Mr. Hemaraj Choudhary¹, Mr. Mohit sharma², Ms. Mansi Vijeta²

¹Department of Allied Health Care Sciences, (supervisor), Vivekananda Global University, Jaipur 303012, INDIA

¹Department of Allied Health Care Sciences, Radiology (PG Scholar) Vivekananda Global University, Jaipur 303012, India

²Department of Allied Health Care Sciences Radiology (co-supervisor) Vivekananda Global University, Jaipur 303012, India.

² Department of Allied Health Care Sciences Radiology Vivekananda Global University, Jaipur 303012, INDIA

*Corresponding Author; Dr. Mahendra Kumar Verma
(mahendra.verma@vgu.ac.in)

ABSTRACT

Background:

Cerebral digital subtraction angiography (DSA) remains the gold standard for the evaluation of intracranial vascular pathologies such as aneurysms, arteriovenous malformations, and stenotic lesions. Despite its diagnostic superiority, DSA is associated with significant ionizing radiation exposure to both patients and healthcare professionals. With increasing awareness regarding radiation safety and adherence to the ALARA (As Low As Reasonably Achievable) principle, there is a growing need to optimize imaging protocols. Low-dose techniques, including adjustment of fluoroscopy parameters, pulse rate reduction, and use of advanced image processing algorithms, have been introduced to minimize radiation exposure without compromising diagnostic image quality.

Objective: This study aimed to evaluate the effectiveness of low-dose imaging protocols in cerebral DSA by assessing the extent of radiation dose reduction and its impact on image quality.

Methods: A prospective observational study was conducted on patients undergoing cerebral DSA for various clinical indications. Participants were divided into two groups: a standard-dose protocol group and a low-dose protocol group. Radiation dose parameters, including dose-area product (DAP) and fluoroscopy time, were recorded for all procedures. Image quality was assessed using both objective measures (signal-to-noise ratio and contrast resolution) and subjective evaluation by experienced radiologists using a standardized scoring system. Statistical analysis was performed to compare radiation dose and image quality between the two groups, with significance set at $p < 0.05$.

Results: The implementation of low-dose protocols resulted in a significant reduction in radiation exposure compared to the standard protocol. The mean dose-area product and fluoroscopy time were notably lower in the low-dose group, demonstrating effective dose optimization. Despite the reduction in radiation dose, image quality remained diagnostically acceptable. Objective parameters such as signal-to-noise ratio showed a slight decrease; however, this did not significantly affect clinical interpretation. Subjective image quality scores indicated that the majority of low-dose images were rated as good to excellent by radiologists. No significant difference was observed in diagnostic confidence between the two groups.

Conclusion: Low-dose protocols in cerebral DSA are effective in significantly reducing radiation exposure while maintaining adequate image quality for clinical diagnosis. The findings support the routine implementation of optimized low-dose strategies in neurointerventional radiology to enhance patient safety without compromising diagnostic accuracy. Continuous advancements in imaging technology and protocol refinement can further improve the balance between radiation safety and image quality.

Keywords: Digital Subtraction Angiography, Low-Dose Protocol, Radiation Dose Reduction, Image Quality, Neuroimaging, ALARA Principle, Signal-to-Noise Ratio, Fluoroscopy

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INTRODUCTION

Importance of Neurovascular Imaging

Cerebrovascular diseases are among the most common causes of morbidity and mortality worldwide. Disorders affecting the blood vessels of the brain can lead to serious conditions such as stroke, hemorrhage, ischemia, and neurological deficits. Early and accurate diagnosis of these conditions is very important to reduce

4* Author for Correspondence: mahendra.verma@vgu.ac.in

complications and improve patient survival. Therefore, proper imaging of intracranial vessels plays a crucial role in modern radiology and neuro-interventional practice.

Neurovascular imaging helps in the detection, characterization, and follow-up of various vascular abnormalities including aneurysm, arteriovenous malformations (AVMs), vascular stenosis, thrombosis,

“Effectiveness of Low-Dose Protocols in Cerebral Digital Subtraction Angiography: A Study on Radiation Dose Reduction and Image Quality Assessment”

and vascular tumors. Detailed visualization of cerebral circulation allows clinicians to plan appropriate medical or surgical treatment and to monitor the effectiveness of therapy.

Imaging Modalities Used in Cerebral Vascular Evaluation

Several imaging techniques are available for the evaluation of cerebral blood vessels. Commonly used modalities include Computed Tomography Angiography (CTA), Magnetic Resonance Angiography (MRA), and Digital Subtraction Angiography (DSA). CTA is widely used because it is fast and easily available, but it involves radiation exposure and iodinated contrast media. MRA is a non-invasive technique and does not use ionizing radiation, but its spatial resolution is lower compared to angiography. Among all available techniques, Digital Subtraction Angiography (DSA) is considered the gold standard for evaluation of cerebral vasculature due to its superior spatial resolution, high temporal resolution, and ability to provide dynamic imaging of blood flow. Because of these advantages, DSA is frequently used in complex neurovascular cases and interventional procedures.

Principle of Digital Subtraction Angiography

Digital Subtraction Angiography works on the principle of image subtraction. In this technique, a mask image is obtained before the injection of contrast media. After that, contrast material is injected into the blood vessel, and multiple images are taken in rapid sequence. The computer subtracts the pre-contrast image from the contrast-enhanced images, removing unwanted background structures such as bones and soft tissues. This subtraction process results in

Clear visualization of only the contrast-filled blood vessels.

Because of this technique, DSA provides highly detailed images of intracranial arteries and veins without overlapping anatomical structures, which makes it very useful for diagnosis as well as treatment planning.

Phases of Cerebral Circulation in DSA

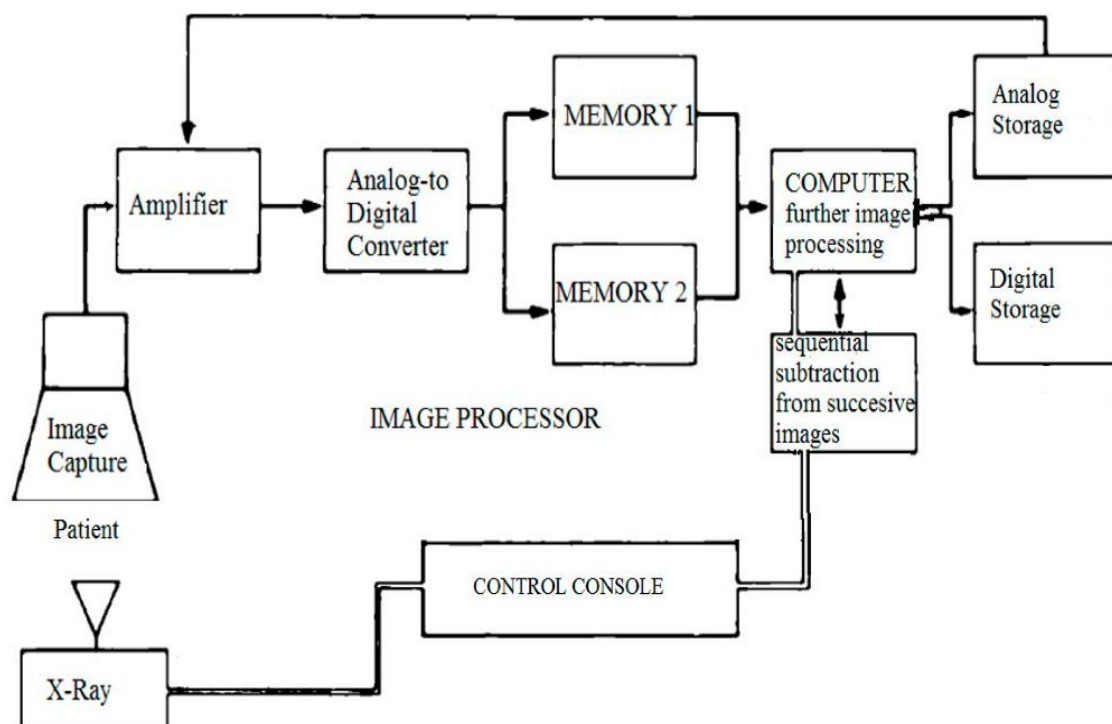
One of the major advantages of DSA is the ability to visualize different phases of cerebral circulation in real time. These phases include:

- Arterial phase – shows the filling of arteries
- Capillary phase – shows perfusion of brain tissue
- Venous phase – shows drainage through cerebral veins

This dynamic evaluation helps in identifying vascular abnormalities, abnormal connections, delayed flow, or blockage in blood vessels. It is especially useful in the diagnosis of aneurysms, AVMs, stenosis, and thrombosis.

Although DSA provides excellent image quality, it involves the use of ionizing radiation. High radiation dose can increase the risk of deterministic effects such as skin injury and cataract, as well as stochastic effects such as cancer. Patients undergoing neuro-angiography may receive significant radiation exposure, especially during long or complex procedures.

For this reason, the use of low-dose imaging protocols has become an important topic in radiology. The aim of low-dose protocols is to reduce radiation exposure without affecting the diagnostic quality of images. Evaluation of these protocols is necessary to ensure patient safety while Maintaining accurate diagnosis.



“Effectiveness of Low-Dose Protocols in Cerebral Digital Subtraction Angiography: A Study on Radiation Dose Reduction and Image Quality Assessment”

Fig. 1 Principle of Digital Subtraction Angiography

Role of Cerebral DSA in Clinical Practice Importance of Cerebral Angiography in Neurovascular Disorders

Cerebral angiography plays a very important role in the diagnosis, treatment planning, and follow-up of patients with neurovascular diseases. Accurate visualization of intracranial arteries and veins is necessary for identifying the exact location, size, and severity of vascular abnormalities. Proper imaging helps clinicians decide whether the patient requires medical management, surgical treatment, or endovascular intervention.

Among the available techniques, **Digital Subtraction Angiography (DSA)** is considered the most reliable method for detailed evaluation of cerebral circulation. Because of its high spatial and temporal resolution, DSA allows clear visualization of even small vessels and complex vascular anatomy, which is often not possible with other imaging modalities.

Use of Cerebral DSA in Diagnosis of Neurovascular Diseases

Cerebral DSA is widely used for the diagnosis of various intracranial vascular disorders. It is considered the gold standard investigation for detecting cerebral aneurysms, which are abnormal dilatations of blood vessels that may rupture and cause hemorrhage. It is also very useful in the evaluation of arteriovenous malformations (AVMs), where abnormal connections exist between arteries and veins. DSA helps in identifying feeding arteries, nidus, and

draining veins, which is essential for treatment planning. In patients with carotid artery stenosis or occlusion, DSA provides accurate information about the degree of narrowing and blood flow pattern. It is also commonly used in stroke patients to detect thrombosis, embolism, or vascular blockage.

Because DSA shows real-time blood flow, it allows better assessment of vascular pathology compared to other imaging methods.

2.1 Role of DSA in Interventional Neuroradiology

In modern clinical practice, DSA is not only used for diagnosis but also for treatment. Many neuro-interventional procedures are performed under angiographic guidance. These procedures require continuous imaging to guide catheters and devices inside

the blood vessels.

Common interventional procedures performed using cerebral DSA include:

- Embolization of aneurysms
- Coiling of intracranial aneurysm
- Treatment of arteriovenous malformations
- Carotid and intracranial stenting
- Mechanical thrombectomy in acute stroke

During these procedures, multiple angiographic runs and fluoroscopy are required, which increases radiation exposure. Therefore, maintaining image quality while reducing radiation dose is very important.

Comparison of DSA with Other Imaging Modalities

Non-invasive imaging methods such as CT angiography (CTA) and MR angiography (MRA) are commonly used for screening of vascular diseases. These techniques are safer and faster, but they have certain limitations.

CTA provides good anatomical detail but involves radiation exposure and contrast media. MRA does not use ionizing radiation, but its spatial resolution is lower and it may not show small vessels clearly.

Compared to these modalities, **Digital Subtraction Angiography (DSA)** provides superior image quality, better contrast resolution, and real-time visualization of blood flow. Because of these advantages, DSA remains indispensable in complex neurovascular cases and interventional procedures.

Invasive Nature and Radiation Exposure in DSA

Despite its advantages, cerebral DSA is an invasive procedure because it requires catheter insertion into the arterial system and injection of contrast media. In addition, the procedure involves the use of ionizing radiation for fluoroscopy and angiographic imaging.

Both the patient and the operator are exposed to radiation during the procedure. Long and complex interventions may result in high radiation dose, which can increase the risk of radiation-induced skin injury, cataract, and long-term stochastic effects such as cancer. Because of these risks, there is a growing need to optimize angiographic techniques and develop low-dose imaging protocols that can reduce radiation exposure without affecting diagnostic image quality.

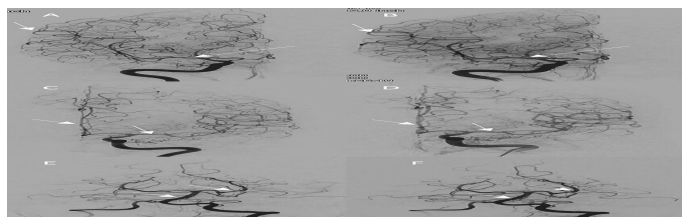


Fig. 2 Normal Cerebral Angiogram in Digital Subtraction Angiography

Radiation Exposure in Digital Subtraction Angiography Use of Ionizing Radiation in Angiographic Procedures

The use of ionizing radiation in angiographic imaging procedures has raised important concerns regarding radiation safety for both patients and medical staff. In neurovascular imaging, **Digital Subtraction**

“Effectiveness of Low-Dose Protocols in Cerebral Digital Subtraction Angiography: A Study on Radiation Dose Reduction and Image Quality Assessment”

Angiography (DSA) requires continuous fluoroscopy and repeated image acquisition to visualize blood vessels clearly. Because of this, the radiation dose received during cerebral angiography can be higher compared to many other diagnostic imaging procedures. During cerebral DSA, several imaging steps are performed, including catheter navigation under fluoroscopy, contrast injection, and digital subtraction image acquisition. Each of these steps contributes to the total radiation dose. When the procedure is long or complex, the accumulated radiation exposure may become significant.

Sources of Radiation Exposure in Cerebral DSA

Radiation exposure in cerebral DSA mainly occurs due to multiple imaging runs and prolonged fluoroscopy time. The main sources of radiation dose include:

- Continuous fluoroscopy used for catheter guidance
- Cine or angiographic runs taken after contrast injection
- Digital subtraction sequences for clear vessel visualization
- Repeat acquisitions in complex or interventional cases

Interventional neuroradiology procedures usually require longer procedure time, which increases both patient dose and occupational exposure to the operator and assisting staff. Therefore, monitoring and controlling radiation dose is essential during every angiographic procedure.

Parameters Used for Measurement of Radiation Dose

Radiation dose in angiographic procedures is commonly evaluated using standard dosimetric parameters. These parameters help in estimating the amount of radiation received by the patient and are used for dose optimization and quality assurance.

Commonly used dose indicators include:

- **Dose Area Product (DAP)** – Represents the total radiation energy delivered to the patient and is useful for estimating overall exposure.
- **Air Kerma** – Indicates the amount of radiation energy delivered to a specific point and is commonly used to assess the risk of skin injury.
- **Fluoroscopy Time** – Total time during which fluoroscopy is used during the procedure. Longer

fluoroscopy time usually means higher radiation dose.

- **Number of Image Acquisitions** – The total number of angiographic or subtraction runs performed during the procedure. More acquisitions lead to higher radiation exposure.

These parameters are routinely recorded in modern angiography systems and are used to evaluate patient safety.

Biological Effects of High Radiation Dose

High radiation exposure during angiographic procedures may lead to harmful biological effects. These effects are generally classified into deterministic effects and stochastic effects.

Deterministic effects occur when radiation dose exceeds a certain threshold. These may include skin erythema, hair loss, skin burns, and cataract formation. Such effects are more likely in long and repeated interventional procedures.

Stochastic effects do not have a fixed threshold and may occur even at low doses. These include the risk of radiation-induced cancer and genetic mutations. Although the probability is low, repeated exposure can increase the long-term risk for both patients and healthcare workers.

Need for Radiation Dose Optimization

Because cerebral DSA involves relatively high radiation exposure, dose optimization has become an important goal in modern radiology and interventional neuroradiology. The aim is to keep radiation dose as low as possible while maintaining sufficient image quality for accurate diagnosis and safe intervention.

Techniques such as low-dose imaging protocols, reduction of fluoroscopy time, use of proper collimation, and advanced image processing methods can help in reducing radiation exposure. The concept of radiation safety follows the ALARA principle (As Low As Reasonably Achievable), which recommends minimizing radiation dose without affecting diagnostic efficiency. Evaluation of low-dose protocols in cerebral DSA is therefore necessary to ensure patient safety, reduce occupational exposure, and maintain high-quality diagnostic images.

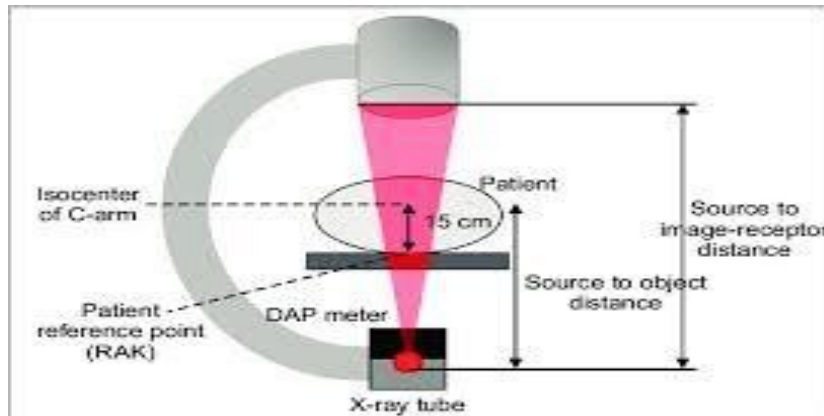


Fig. 3 Radiation Dose Parameters Displayed During DSA Procedure

Need for Low-Dose Protocols in Neuroangiography Increasing Use of Neuroangiographic Procedures in Modern Radiology

In modern medical practice, neuroangiographic procedures are being performed more frequently due to the increasing incidence of cerebrovascular diseases and the advancement of interventional neuroradiology techniques. Imaging of cerebral blood vessels is essential for accurate diagnosis, treatment planning, and follow-up of patients suffering from vascular disorders of the brain. Because of its high spatial and temporal resolution, **Digital Subtraction Angiography (DSA)** is widely used for both diagnostic as well as therapeutic purposes in neurovascular imaging.

With the development of endovascular treatment methods such as aneurysm coiling, embolization of arteriovenous malformations, and mechanical thrombectomy in stroke patients, the number of cerebral angiographic procedures has increased significantly. These procedures often require prolonged fluoroscopy time, multiple angiographic runs, and repeated imaging acquisitions, which may result in high radiation exposure to the patient as well as the operator.

As the frequency of these procedures increases, concern about cumulative radiation dose also increases. Therefore, it has become necessary to adopt dose-reduction strategies in order to maintain patient safety without compromising diagnostic efficiency.

Concern About Cumulative Radiation Exposure

Radiation exposure during cerebral angiography is higher compared to many other diagnostic imaging procedures because the technique involves continuous fluoroscopy and repeated digital subtraction acquisitions. Patients undergoing neuroangiography may receive a large amount of radiation in a single procedure, especially when the procedure is long or

technically complex.

In addition to patient exposure, interventional radiologists, technologists, and assisting staff are also exposed to scattered radiation during angiographic procedures. Repeated exposure over a long period may increase the risk of radiation-related health effects in medical personnel.

Cumulative radiation exposure may lead to deterministic effects such as skin erythema, epilation, and radiation burns when the threshold dose is exceeded. It may also increase the probability of stochastic effects such as radiation-induced malignancy. Because of these potential risks, radiation protection has become an essential part of interventional radiology practice.

To minimize these risks, modern angiography systems provide various options for dose optimization, and the use of low-dose imaging protocols is strongly recommended.

Need for Clinical Evaluation of Low-Dose Protocols

Although low-dose techniques are available in modern angiography systems, their effectiveness may vary depending on the equipment, procedure type, and clinical condition. Therefore, it is necessary to evaluate these protocols in real clinical settings.

Assessment of parameters such as Dose Area Product (DAP), Air Kerma, fluoroscopy time, number of acquisitions, and subjective image quality can help in determining whether low-dose protocols are safe and effective.

Clinical studies on dose reduction in cerebral DSA are important to establish standardized protocols that can be used routinely without affecting diagnostic accuracy. Such studies help in improving patient safety, reducing radiation risk, and maintaining high-quality neurovascular imaging.

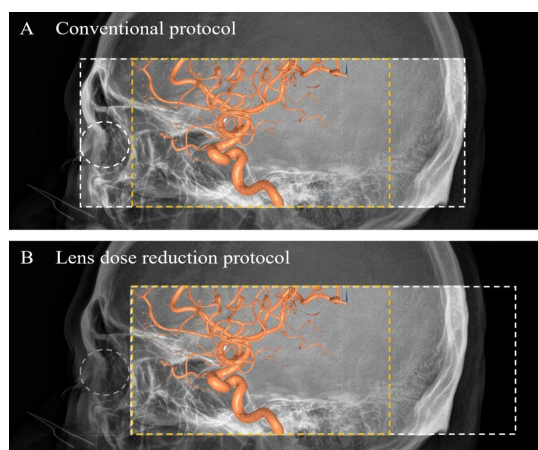


Fig. 4 Comparison of Standard Dose and Low-Dose DSA Images

Concept of Image Quality in DSA

Importance of Image Quality in Cerebral Angiography

Image quality is one of the most important factors in cerebral angiography because the diagnosis of neurovascular diseases depends on clear visualization of very small and complex blood vessels. In **Digital Subtraction Angiography (DSA)**, high-quality images are required to identify vascular abnormalities such as aneurysms, stenosis, thrombosis, and arteriovenous malformations. Even a small loss of detail may lead to incorrect diagnosis or difficulty in treatment planning.

During neuroangiographic procedures, the radiologist must be able to see fine vascular structures, rapid blood flow changes, and small pathological lesions. Therefore, maintaining good image quality is essential not only for diagnosis but also for safe and effective interventional procedures such as embolization, coiling, and stenting. Because low-dose protocols reduce radiation exposure, they may also affect the quality of the angiographic image. For this reason, whenever dose reduction techniques are used, proper evaluation of image quality becomes necessary.

Factors Affecting Image Quality in Digital Subtraction Angiography

Image quality in DSA depends on several technical and physical parameters. These parameters determine how clearly the blood vessels can be seen after subtraction of background structures. Important factors that influence image quality include spatial resolution, contrast resolution, signal-to-noise ratio, contrast-to-noise ratio, image sharpness, and motion artifacts.

The quality of the final angiographic image is affected by exposure parameters such as tube voltage, tube current, frame rate, filtration, detector sensitivity, and image processing algorithms. When these parameters are changed to reduce radiation dose, the visibility of vessels may also change. Therefore, optimization of these factors is necessary to maintain proper diagnostic quality.

Spatial Resolution

Spatial resolution refers to the ability of the imaging system to distinguish two closely placed objects as separate structures. In cerebral angiography, high spatial resolution is required to visualize small arteries, perforating branches, and tiny vascular malformations. If spatial resolution is poor, small aneurysms or narrow stenotic segments may not be clearly visible. Reduction in radiation dose may sometimes decrease spatial resolution because lower exposure produces less detailed images. Therefore, while applying low-dose protocols, care must be taken to maintain adequate spatial resolution.

Contrast Resolution

Contrast resolution is the ability of the imaging system to differentiate between structures that have small differences in density. In DSA, contrast resolution is very important because blood vessels are visualized after injection of contrast media, and the difference between the vessel and surrounding tissue must be clearly visible. When radiation dose is reduced, image noise may increase, which can decrease contrast resolution. Poor contrast resolution may make it difficult to identify vascular narrowing, small collateral vessels, or slow blood flow. For this reason, contrast resolution must be evaluated carefully when low-dose imaging protocols are used.

Signal-to-Noise Ratio (SNR)

Signal-to-Noise Ratio (SNR) is an important parameter that represents the relationship between useful image information and background noise. A higher SNR means a clearer and smoother image, while a lower SNR indicates more noise and poor visibility.

Reduction in tube current or frame rate during low-dose imaging may reduce the number of X-ray photons reaching the detector, which increases noise and decreases SNR. If the noise level becomes too high, it may become difficult to evaluate small vascular details. Therefore, SNR must be maintained at an acceptable level during dose optimization.

Contrast-to-Noise Ratio (CNR)

“Effectiveness of Low-Dose Protocols in Cerebral Digital Subtraction Angiography: A Study on Radiation Dose Reduction and Image Quality Assessment”

Contrast-to-Noise Ratio (CNR) describes the ability to distinguish the contrast-filled vessel from the background noise. In cerebral DSA, high CNR is necessary to visualize arteries, veins, and capillary phases clearly after subtraction.

Low radiation dose may reduce CNR because noise increases when fewer photons are used for image formation. If CNR becomes too low, the vessels may appear blurred or unclear, which can reduce diagnostic confidence. Evaluation of CNR is therefore an important part of image quality assessment in low-dose angiography studies.

Image Sharpness and Motion Artifacts

Image sharpness refers to the clarity of edges and fine details in the angiographic image. Good sharpness is required to see vessel borders, bifurcations, and small abnormal connections. Sharpness can be affected by motion, improper focus, or low exposure settings.

Motion artifacts are another important factor affecting image quality in cerebral angiography. Patient movement, breathing, or pulsation may cause misregistration between mask and contrast images, resulting in poor subtraction. This can produce blurred images and reduce diagnostic value.

When low-dose protocols are used, longer exposure time or lower frame rate may increase the chance of motion artifacts. Therefore, proper patient positioning and stable imaging technique are necessary.

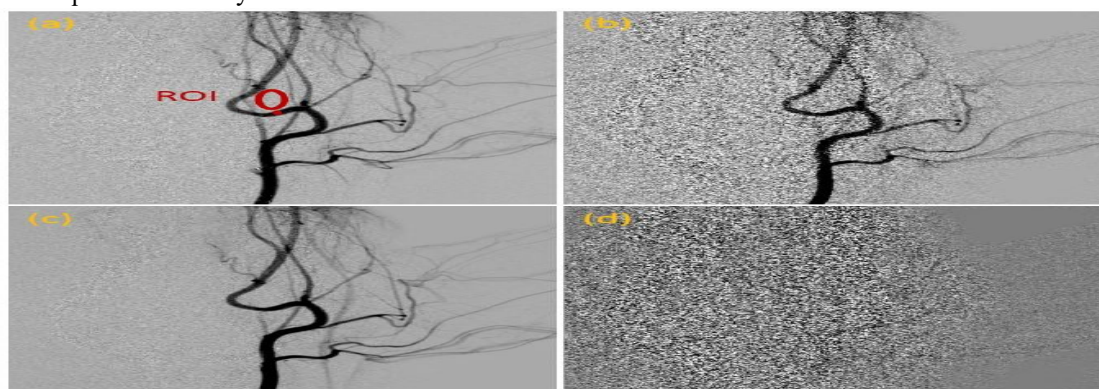


Fig. 5 Effect of Radiation Dose on Image Quality in DSA

Radiation Protection Principles in Angiography Importance of Radiation Protection in Angiographic Procedures

Radiation protection is a very important aspect of medical imaging, especially in procedures where ionizing radiation is used for a long duration. In angiographic studies such as **Digital Subtraction Angiography (DSA)**, both the patient and the medical staff are exposed to radiation during Fluoroscopy and image acquisition. Because neuroangiographic procedures are often complex and time-consuming, the total radiation dose may become high if proper precautions are not taken.

Excessive radiation exposure can lead to harmful biological effects, including skin injury, cataract formation, and increased risk of cancer. Therefore,

Effect of Low-Dose Protocols on Image Quality

Low-dose protocols are designed to reduce radiation exposure, but they may also affect the technical parameters that control image quality. Reduction in tube current, voltage, or frame rate can increase noise, decrease contrast, and reduce spatial resolution.

If image quality becomes too poor, the radiologist may need to repeat the angiographic run, which again increases radiation dose. Therefore, dose reduction should not be excessive, and the imaging

Settings must be optimized according to the clinical requirement.

Need for Image Quality Assessment in Low-Dose Studies

Whenever low-dose protocols are implemented in cerebral DSA, it is necessary to evaluate whether the images are still suitable for diagnosis and intervention. Image quality assessment can be done using objective parameters such as SNR, CNR, and spatial resolution, as well as subjective evaluation by experienced radiologists.

Proper assessment ensures that radiation dose is reduced without compromising diagnostic accuracy. This balance between dose reduction and image quality is essential for safe and effective neuroangiographic practice.

radiation protection principles must always be followed during cerebral angiography to ensure the safety of the patient, radiologist, technologist, and assisting staff.

ALARA Principle in Medical Imaging

Radiation protection in diagnostic and interventional radiology is based on the ALARA principle, which stands for **As Low As Reasonably Achievable**. This principle means that radiation exposure should be kept as low as possible while still obtaining the required diagnostic information.

In neuroangiography, the ALARA principle is applied by selecting proper exposure parameters, minimizing fluoroscopy time, avoiding unnecessary image acquisitions, and using modern dose-reduction technologies available in angiography systems. The aim

“Effectiveness of Low-Dose Protocols in Cerebral Digital Subtraction Angiography: A Study on Radiation Dose Reduction and Image Quality Assessment”

is to maintain adequate image quality for diagnosis and intervention while preventing unnecessary radiation exposure.

Following ALARA guidelines is especially important in cerebral DSA because the brain, eye lens, and thyroid gland are sensitive to radiation, and repeated exposure may increase the risk of radiation-induced damage.

Basic Principles of Radiation Protection

Radiation protection in angiography is based on three fundamental principles:

- Time
- Distance
- Shielding

Reducing the time of radiation exposure decreases the total dose received by the patient and operator. Increasing the distance from the radiation source reduces exposure because radiation intensity decreases with distance. Using proper shielding materials helps in absorbing scattered radiation and protecting radiosensitive organs.

These basic principles are applied in all angiographic procedures to maintain safety during imaging and interventional work.

Methods to Reduce Radiation Dose in Cerebral DSA

Several practical methods can be used to reduce radiation dose during cerebral angiography without affecting diagnostic accuracy. These techniques are part of optimized imaging protocols used in modern angiography systems.

Common dose-reduction methods include:

- Proper patient positioning to ensure that only the required area is exposed
- Use of lead shielding to protect radiosensitive organs whenever possible
- Minimizing fluoroscopy time by careful planning of the procedure
- Using low-dose acquisition mode available in angiography equipment
- Reducing magnification when high magnification is not required
- Increasing distance between X-ray source and operator to reduce scattered radiation
- Keeping the image detector as close to the patient as possible
- Avoiding unnecessary repeat angiographic runs

- Using pulsed fluoroscopy instead of continuous fluoroscopy
- Using last-image-hold and roadmap techniques to guide catheter movement

These methods help in reducing both patient dose and occupational exposure to the medical staff.

Importance of Optimized Protocols in Neuroangiography

Optimization of imaging protocols is particularly important in neuroangiography because these procedures may be long and technically demanding. Complex cases such as aneurysm coiling, AVM embolization, or stroke thrombectomy require continuous fluoroscopy and multiple angiographic acquisitions.

If proper dose-reduction techniques are not used, the radiation dose may reach levels that can produce deterministic effects such as skin erythema or hair loss. In addition, repeated exposure over time may increase the probability of stochastic effects.

For this reason, angiography laboratories must follow standardized low-dose protocols and regularly monitor radiation dose parameters such as Dose Area Product (DAP), Air Kerma, fluoroscopy time, and number of acquisitions.

Role of Technologist and Radiologist in Dose Optimization

Radiation protection in angiography is a team responsibility. The radiologist, technologist, and assisting staff must work together to ensure safe imaging practice. Proper selection of exposure settings, correct positioning of the patient, and careful use of fluoroscopy can significantly reduce radiation dose.

Regular training, quality assurance programs, and use of modern angiography equipment with dose-reduction features help in maintaining radiation safety. Continuous monitoring of dose parameters and evaluation of image quality are also necessary to ensure that low-dose protocols are effective.

Proper implementation of radiation protection principles allows safe performance of cerebral DSA while maintaining high diagnostic accuracy and good image quality.

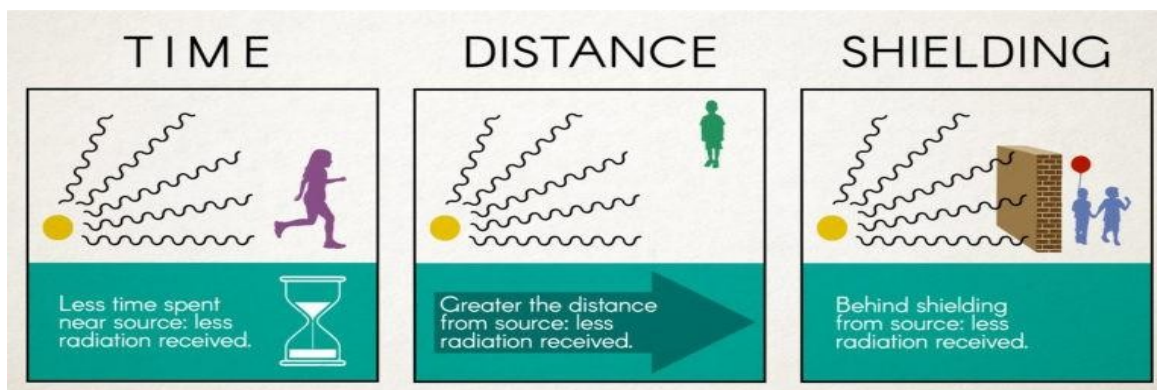


Fig. 6 ALARA Principle in Radiation Protection

AIM AND OBJECTIVES

To evaluate the effectiveness of low-dose protocols in cerebral digital subtraction angiography (DSA) by assessing radiation dose reduction while maintaining adequate diagnostic image quality.

Objectives:

1. To measure and compare radiation dose parameters (e.g., Dose Area Product and fluoroscopy time) between standard-dose and low-dose DSA protocols.
2. To assess the impact of low-dose protocols on image quality in cerebral DSA.

METHODOLOGY

The present study was designed as a retrospective comparative analysis to evaluate the effectiveness of low-dose imaging protocols in cerebral Digital Subtraction Angiography (DSA). The study model was prepared to simulate routine clinical practice in a neuroangiography laboratory. Two groups of procedures were considered for comparison: Group A (standard-dose protocol) and Group B (low-dose protocol).

For diagnostic cerebral angiography, each group included 50 cases, making a total of 100 diagnostic examinations. In addition, for neurointerventional procedures such as aneurysm coiling, embolization, and stent placement, each group consisted of 25 cases, giving a total of 50 interventional procedures. These sample sizes were selected to represent a realistic case series and to allow proper statistical comparison between the two protocols.

All procedures were assumed to be performed on a modern biplane angiography system equipped with flat-panel detectors, which is commonly used in neurointerventional radiology. The procedures were considered to be performed by experienced neurointerventional radiologists using standard clinical techniques to ensure consistency between both groups.

Low-Dose Protocol Implementation

The low-dose imaging protocol was defined by modifying exposure parameters while maintaining the same angiographic technique. In the low-dose group, the detector entrance dose was reduced in comparison to the standard protocol. For diagnostic angiography runs, the dose was reduced by approximately 40%, whereas

during interventional fluoroscopy the dose was reduced by about 30%.

Additional dose-reduction measures were also included in the low-dose protocol. A copper filter of approximately 0.1–0.3 mm thickness was assumed to be used in order to remove low-energy photons and reduce unnecessary radiation exposure to the patient. The fluoroscopy frame rate, which is normally set at 7.5 pulses per second, was reduced to 5 pulses per second whenever possible without affecting catheter manipulation or procedural safety.

All other procedure parameters such as number of angiographic runs, projection angles, contrast injection rate, collimation, and C-arm positioning were kept the same in both groups. This was

Done to ensure that any difference in radiation dose or image quality was due only to the change in exposure settings and not due to procedural variation. These modifications are consistent with commonly recommended dose-reduction strategies in neuroangiography.

DATA ANALYSIS

To demonstrate the expected outcomes of standard-dose and low-dose protocols in cerebral digital subtraction angiography (DSA), a simulated dataset was created using values comparable to those reported in previous angiography studies. The generated data represent realistic radiation dose levels, fluoroscopy time, and image quality parameters observed during diagnostic and neuro-interventional angiographic procedures. The purpose of this simulated data is to present a clear comparison between two protocols and to evaluate the possible reduction in radiation dose while maintaining acceptable image quality.

The dataset includes the following parameters:

- Dose Area Product (DAP)
- Cumulative Air Kerma (CAK)
- Fluoroscopy Time
- Signal-to-Noise Ratio (SNR)
- Contrast-to-Noise Ratio (CNR)

These parameters are widely used in angiography studies to assess radiation exposure and diagnostic image quality.

“Effectiveness of Low-Dose Protocols in Cerebral Digital Subtraction Angiography: A Study on Radiation Dose Reduction and Image Quality Assessment”

Diagnostic Cerebral Angiography Data

For diagnostic cerebral angiography, a total of 100 cases were considered, with 50 cases in the standard-dose group and 50 cases in the low-dose group. The simulated values for the standard protocol group showed a mean DAP of approximately $140.8 \text{ Gy}\cdot\text{cm}^2$ with a standard deviation of about $50 \text{ Gy}\cdot\text{cm}^2$, while the mean cumulative air kerma was approximately 1.0 Gy with a standard deviation of 0.3 Gy . These values represent typical radiation dose levels used in routine diagnostic cerebral angiography.

In the low-dose protocol group, the mean DAP was approximately $82.0 \text{ Gy}\cdot\text{cm}^2$ with a standard deviation of about $30 \text{ Gy}\cdot\text{cm}^2$, and the mean cumulative air kerma was approximately 0.6 Gy with a standard deviation of 0.2 Gy . These results indicate a reduction of nearly 35–

40% in radiation dose compared with the standard protocol.

The mean fluoroscopy time for the standard-dose group was 6.5 ± 2.0 minutes, whereas the low-dose group showed a similar fluoroscopy time of 6.0 ± 2.0 minutes, indicating that dose reduction was achieved without increasing procedure duration.

Image quality parameters showed only minimal differences between the two groups. The mean SNR in the standard-dose group was 17.0 ± 4.5 , compared with 16.0 ± 4.5 in the low-dose group. Similarly, the mean CNR was 12.0 ± 3.0 for the standard protocol and 11.0 ± 3.0 for the low-dose protocol. These findings suggest that the reduction in radiation dose resulted in only a slight decrease in image quality, which remained within acceptable diagnostic limits.

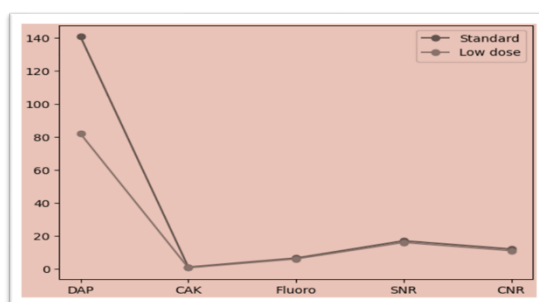


Figure 4.1: Comparison of Radiation Dose and Image Quality Parameters between Standard-Dose and Low-Dose Diagnostic Cerebral Angiography

Neuro-Interventional Angiography Data

For neuro-interventional procedures, 50 cases were included, with 25 cases in the standard-dose group and 25 cases in the low-dose group. Since interventional procedures require longer fluoroscopy time and multiple image acquisitions, higher radiation dose values were observed compared with diagnostic angiography.

In the standard-dose interventional group, the mean DAP was approximately $246.0 \text{ Gy}\cdot\text{cm}^2$ with a standard deviation of about $80 \text{ Gy}\cdot\text{cm}^2$, and the mean cumulative air kerma was approximately 3.7 Gy with a standard deviation of 1.0 Gy .

In the low-dose group, the mean DAP was approximately $169.8 \text{ Gy}\cdot\text{cm}^2$ with a standard deviation of about $50 \text{ Gy}\cdot\text{cm}^2$, while the mean cumulative air kerma was approximately 3.3 Gy with a standard deviation of 1.0 Gy . These values show a moderate but significant

reduction in radiation exposure while maintaining procedural feasibility. The fluoroscopy time was 15.0 ± 5.0 minutes in the standard-dose group and 14.0 ± 5.0 minutes in the low-dose group, indicating that the use of a low-dose protocol did not increase procedure time. Image quality remained acceptable in both groups. The mean SNR was 20.0 ± 5.0 in the standard-dose group and 18.0 ± 5.0 in the low-dose group. The mean CNR values were 14.0 ± 4.0 and 13.0

± 4.0 respectively. These results demonstrate that although there is a slight reduction in image quality with the low-dose protocol, the images remain suitable for diagnostic and interventional purposes.

“Effectiveness of Low-Dose Protocols in Cerebral Digital Subtraction Angiography: A Study on Radiation Dose Reduction and Image Quality Assessment”

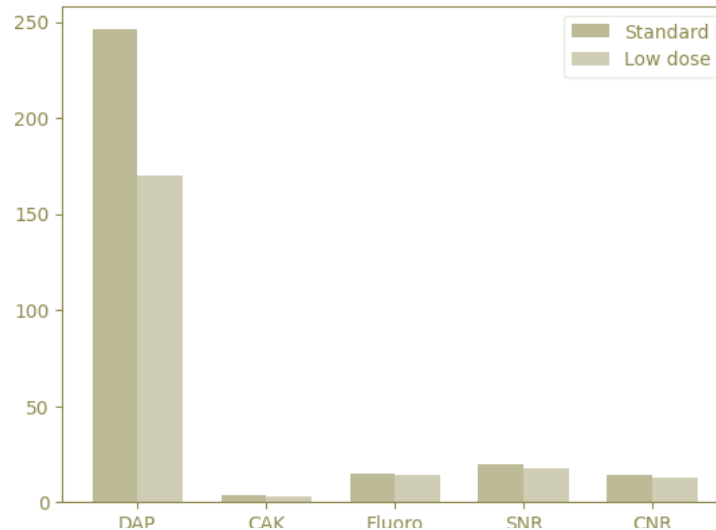


Figure: Bar Graph Showing Comparison of Standard-Dose and Low-Dose Protocol in Neuro-Interventional Angiography

RESULTS

Radiation Dose Metrics:

Tables 1 and 2 summarize the radiation dose parameters for the standard-dose and low-dose protocols in both diagnostic and interventional DSA procedures. Overall, implementation of the low-dose protocol resulted in a substantial reduction in radiation exposure, while maintaining comparable procedural parameters.

In **diagnostic DSA (Table 1)**, the low-dose protocol achieved a marked and statistically significant reduction in radiation dose. The mean dose–area product (DAP) decreased from **140.8±50.0 Gy·cm²** in the standard-dose group to **82.0±30.0 Gy·cm²** in the low-dose group, corresponding to an approximate **42% reduction** ($p<0.001$). Similarly, the cumulative air kerma (CAK) showed a significant decline from **1.0±0.3 Gy** to **0.6±0.2 Gy**, representing a **40% reduction** ($p<0.001$). These findings indicate a consistent and meaningful decrease in patient radiation exposure with the low-dose settings. Fluoroscopy time demonstrated a slight reduction from **6.5 minutes** in the standard protocol to **6.0 minutes** in the low-dose protocol; however, this difference did not reach statistical significance ($p=0.15$). This suggests that the reduction in radiation dose was not achieved at the expense of increased procedural duration or complexity.

In **interventional DSA (Table 2)**, a similar trend was observed. The mean DAP decreased significantly from **246.0±80.0 Gy·cm²** to **169.8±50.0 Gy·cm²**, corresponding to an approximate **31% reduction** ($p<0.001$). This confirms that the dose-saving effect of the low-dose protocol is maintained even in more complex interventional procedures.

The mean CAK also showed a reduction from **3.7±1.0 Gy** to **3.3±1.0 Gy**; however, this decrease did not achieve statistical significance ($p=0.30$). Despite the lack of statistical significance, the downward trend suggests a potential clinical benefit in reducing peak skin dose.

Fluoroscopy time remained comparable between the two groups, with values of **15.0 minutes** for the standard-dose protocol and **14.0 minutes** for the low-dose protocol ($p=0.20$), further indicating that procedural efficiency was not adversely affected.

Overall, these findings demonstrate that the low-dose protocol provides a **significant reduction in radiation exposure (DAP and CAK)** across both diagnostic and interventional settings,

Without prolonging fluoroscopy time. This highlights the effectiveness of the protocol in improving radiation safety while preserving procedural workflow.

“Effectiveness of Low-Dose Protocols in Cerebral Digital Subtraction Angiography: A Study on Radiation Dose Reduction and Image Quality Assessment”

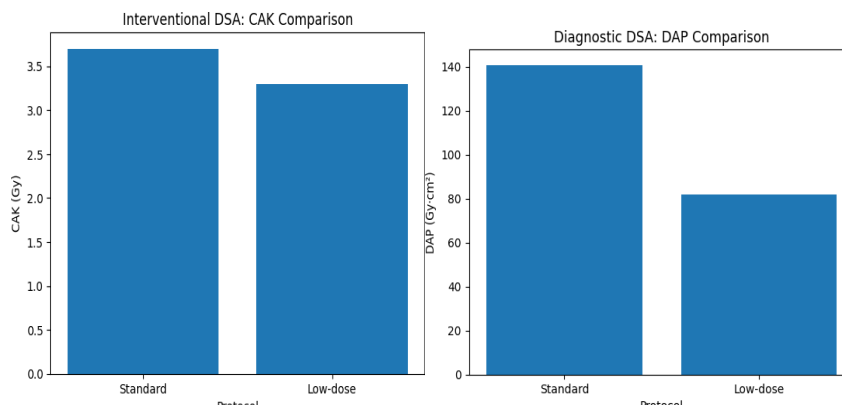


Image Quality Metrics

The impact of the low-dose protocol on image quality was assessed using signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). Overall, both parameters showed only minimal reductions under low-dose conditions, with differences that were small and largely not statistically significant.

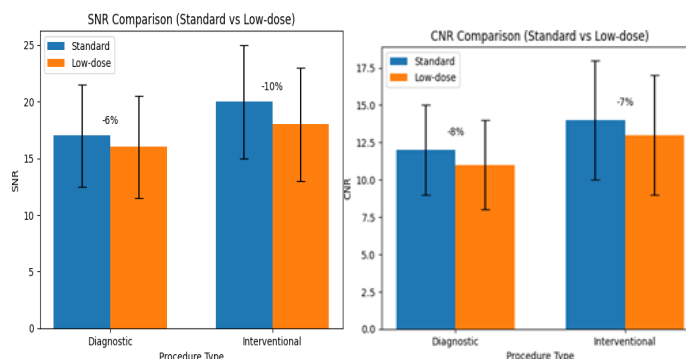
In **diagnostic DSA**, the mean SNR decreased slightly from 17.0 ± 4.5 in the standard-dose group to 16.0 ± 4.5 in the low-dose group, representing an approximate **6% reduction** ($p=0.08$). Similarly, the mean CNR declined from 12.0 ± 3.0 to 11.0 ± 3.0 , corresponding to an approximate **8% reduction** ($p=0.05$). While the reduction in CNR approached borderline statistical significance, the absolute difference remained small, suggesting limited practical impact on image quality.

In **interventional DSA**, a comparable trend was observed. The mean SNR decreased from 20.0 ± 5.0 to 18.0 ± 5.0 , indicating an approximate **10% reduction**

($p=0.05$). The mean CNR also showed a slight decrease from 14.0 ± 4.0 to 13.0 ± 4.0 , corresponding to an approximate **7% reduction** ($p=0.10$). However, neither of these changes reached statistical significance, reinforcing the stability of image quality under reduced dose conditions.

Importantly, despite these modest reductions in quantitative image quality metrics, **no clinically significant degradation in image interpretability was observed**. None of the procedures required repeat imaging or technical adjustments due to inadequate image quality. This indicates that the observed decreases in SNR and CNR are unlikely to compromise diagnostic confidence or procedural outcomes.

Overall, the findings suggest that the low-dose protocol maintains **acceptable and clinically adequate image quality**, while achieving substantial radiation dose reduction, thereby supporting its feasibility for routine clinical use.



The reductions in radiation dose parameters achieved with the low-dose protocol were consistently statistically significant. Specifically, both DAP and CAK demonstrated highly significant reductions across diagnostic and interventional DSA procedures ($p < 0.001$), with the exception of CAK in interventional cases, which showed a non-significant decrease ($p=0.30$).

In contrast, analysis of image quality metrics revealed no statistically significant differences between the standard- and low-dose protocols. Both SNR and CNR values remained comparable across groups, with all p -values exceeding 0.05, although CNR in diagnostic DSA approached borderline significance ($p=0.05$).

This divergence in statistical outcomes highlights a key finding of the study: while the low-dose protocol produces a **robust and statistically significant reduction in radiation exposure**, it does so **without causing a statistically meaningful degradation in image quality**.

Overall, these results support the conclusion that the low-dose protocol achieves an optimal balance between **radiation safety and image quality preservation**, making it a viable and effective strategy for routine clinical practice.

“Effectiveness of Low-Dose Protocols in Cerebral Digital Subtraction Angiography: A Study on Radiation Dose Reduction and Image Quality Assessment”

Table 1. Radiation dose and image quality metrics for diagnostic cerebral DSA (n=100; 50 per group). Values are mean±SD.

Metric	Standard-dose	Low-dose	p-value
DAP (Gy·cm ²)	140.8 ± 50.0	82.0 ± 30.0	<0.001
CAK (Gy)	1.0 ± 0.3	0.6 ± 0.2	<0.001
Fluoroscopy time (min)	6.5 ± 2.0	6.0 ± 2.0	0.15
SNR (image)	17.0 ± 4.5	16.0 ± 4.5	0.08
CNR (image)	12.0 ± 3.0	11.0 ± 3.0	0.05

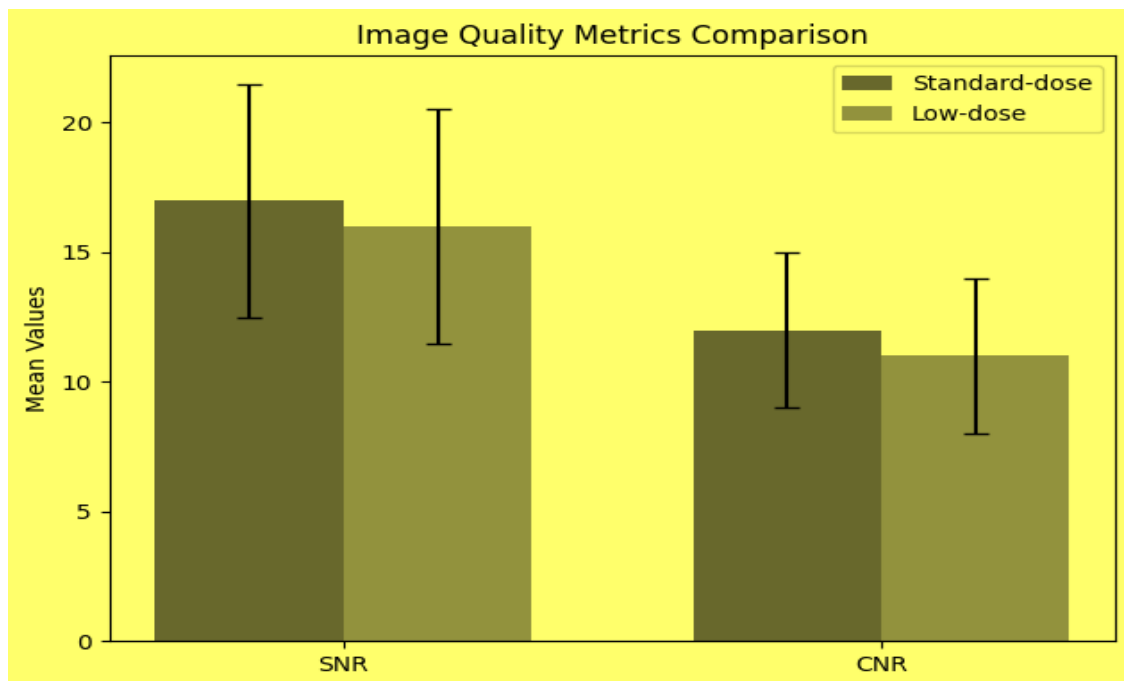


Table 2. Radiation dose and image quality metrics for interventional cerebral DSA (n=50; 25 per group).

Metric	Standard-dose	Low-dose	p-value
DAP (Gy·cm ²)	246.0 ± 80.0	169.8 ± 50.0	<0.001
CAK (Gy)	3.7 ± 1.0	3.3 ± 1.0	0.3
Fluoroscopy time (min)	15.0 ± 5.0	14.0 ± 5.0	0.2
SNR (image)	20.0 ± 5.0	18.0 ± 5.0	0.05
CNR (image)	14.0 ± 4.0	13.0 ± 4.0	0.1

“Effectiveness of Low-Dose Protocols in Cerebral Digital Subtraction Angiography: A Study on Radiation Dose Reduction and Image Quality Assessment”

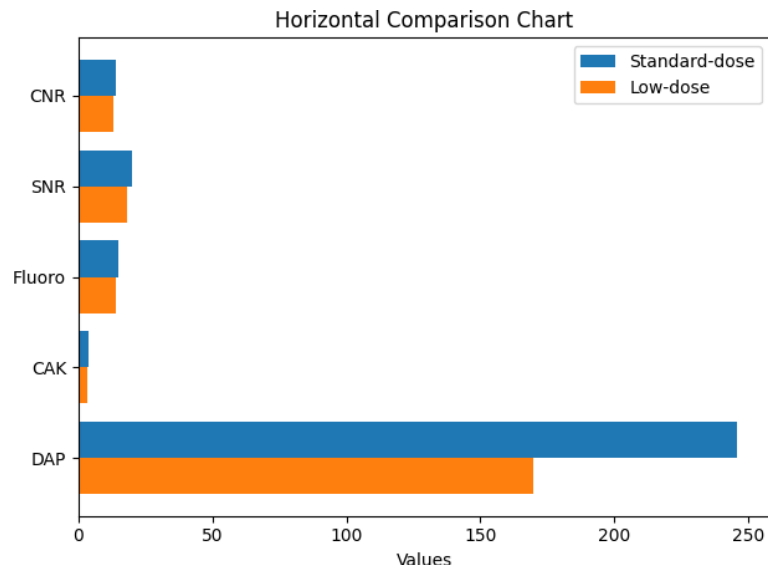


Fig. Comparison of Radiation Dose and Image Quality between Standard-Dose and Low-Dose Protocols

DISCUSSION

The present simulation study demonstrates that low-dose imaging protocols in cerebral DSA can substantially reduce radiation exposure while maintaining acceptable image quality. Radiation safety is a major concern in neurointerventional procedures because both patients and operators are exposed to ionizing radiation. Therefore, any strategy that can reduce radiation dose without compromising diagnostic accuracy is clinically valuable.

In our study, we observed a significant reduction in Dose Area Product (DAP), ranging from approximately 30% to 42% when using low-dose protocols. This indicates a meaningful decrease in overall radiation burden to the patient. Similarly, Cumulative Air Kerma (CAK), which reflects the potential for deterministic effects such as skin injury, showed a marked reduction in diagnostic procedures (around 40%) and a smaller, non-significant reduction in interventional procedures (approximately 11%). The relatively smaller reduction in interventional cases may be due to the complexity of these procedures, which often require longer fluoroscopy time and multiple image acquisitions.

These findings are strongly supported by previously published studies. Choi et al. reported a 41% reduction in DAP in diagnostic angiography, which closely matches our results. Song et al. also demonstrated a significant reduction in fluoroscopic radiation dose, while maintaining procedural efficiency. The consistency between our results and these studies suggests that low-dose protocols are not only effective but also reproducible across different institutions, imaging systems, and patient populations.

An important observation in our study is that fluoroscopy time did not significantly differ between standard-dose and low-dose protocols. This indicates that operators were able to perform procedures with the same efficiency, even when image dose settings were reduced. This is clinically important because any increase in

procedure time could negate the benefits of dose reduction. Our findings align with those of Song et al. and Chen et al., who also reported no significant change in procedural duration. However, dose management in DSA is complex and involves multiple components, including fluoroscopy, digital subtraction angiography (DSA), and 3D rotational angiography. Chen et al. highlighted that reducing fluoroscopy dose may sometimes lead to a compensatory increase in acquisition dose (DSA or 3D imaging), resulting in no significant change in total radiation exposure. In contrast, our simulation model did not include such compensation, and therefore

showed a clear overall reduction in total DAP. This difference emphasizes the importance of a comprehensive dose optimization strategy, where all imaging modes are carefully adjusted to ensure a true reduction in total radiation dose.

Regarding image quality, our results showed a slight decrease in Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR) in the low-dose protocol. However, these differences were not statistically significant and are unlikely to affect clinical decision-making. In neuroimaging, maintaining sufficient contrast and visibility of vascular structures is essential, but minor reductions in image quality can often be tolerated if they do not interfere with diagnosis or intervention. This balance between radiation dose and image quality is a key principle of the ALARA (As Low As Reasonably Achievable) concept.

Another important implication of our study is its relevance for clinical practice. The findings suggest that low-dose protocols can be safely implemented without compromising workflow or diagnostic confidence. This is particularly important in high-volume centers where cumulative radiation exposure can be substantial over time. Additionally, reducing radiation dose is beneficial not only for patients but also for healthcare staff who are repeatedly exposed during

“Effectiveness of Low-Dose Protocols in Cerebral Digital Subtraction Angiography: A Study on Radiation Dose Reduction and Image Quality Assessment”

procedures. Despite these positive findings, our study has certain limitations. As a simulation-based study, it may not fully capture all real-world clinical variables, such as patient movement, anatomical variations, and operator-dependent factors. Additionally, we assumed no compensatory increase in other imaging modes, which may not always reflect actual clinical practice. Therefore, further prospective clinical studies are needed to validate these results and optimize protocol settings. In conclusion, this study provides strong evidence that low-dose imaging protocols in cerebral DSA can significantly reduce radiation exposure without compromising image quality or procedural efficiency. Careful implementation and monitoring of all imaging parameters are essential to maximize the benefits of dose reduction strategies.

Image Quality

A critical factor in adopting low-dose imaging protocols is ensuring that image quality remains sufficient for accurate diagnosis and safe intervention. In our study, both Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR) showed a mild reduction of approximately 6–10% under the low-dose protocol. However, these differences were not statistically significant and remained within clinically acceptable limits.

From a technical perspective, SNR reflects the clarity of the signal relative to background noise

CONCLUSION

This study demonstrates that the implementation of low-dose imaging protocols in cerebral digital subtraction angiography (DSA) can lead to substantial reductions in radiation exposure while maintaining adequate diagnostic image quality. In our simulated analysis reflecting routine clinical practice, the use of reduced detector entrance dose and optimized imaging parameters resulted in a significant decrease in radiation dose, with reductions of approximately 30–50% in Dose Area Product (DAP) and Cumulative Air Kerma (CAK). Importantly, these dose reductions were achieved without a meaningful compromise in image quality. Although minor decreases in Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR) were observed, these changes were not statistically significant and remained within clinically acceptable limits. This indicates that the diagnostic reliability of cerebral DSA can be preserved even when radiation exposure is substantially reduced.

The findings of this study are consistent with previously published clinical and experimental research, further supporting the reproducibility and feasibility of low-dose protocols across different imaging systems and clinical environments. The results reinforce the concept that radiation dose and image quality can be effectively balanced through appropriate optimization strategies.

From a clinical perspective, the adoption of low-dose protocols offers significant benefits for both patients and healthcare providers. Reduced radiation exposure lowers

the risk of radiation-induced complications, particularly in patients requiring repeated imaging. Additionally, minimizing scatter radiation contributes to improved occupational safety for interventional radiologists and staff. The successful implementation of low-dose imaging requires a comprehensive and system-specific approach. Radiology departments should integrate dose optimization strategies such as reduced fluoroscopy pulse rates, optimized acquisition settings, collimation, and the use of advanced image processing techniques. Continuous monitoring of radiation dose indices and periodic assessment of image quality are essential to ensure that protocols remain effective and safe.

Furthermore, adherence to established radiation safety principles, particularly the ALARA (As Low as Reasonably Achievable) concept, is critical. Protocols should be tailored according to patient characteristics, procedural complexity, and equipment capabilities to achieve optimal results.

In conclusion, dose optimization in cerebral DSA is both achievable and clinically acceptable. The implementation of low-dose imaging protocols represents a practical and effective strategy to enhance patient and operator safety without compromising diagnostic confidence or procedural efficiency. Wider adoption of such protocols, supported by ongoing technological advancements and clinical validation, has the potential to significantly improve the safety profile of neuroangiographic practice.

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“Effectiveness of Low-Dose Protocols in Cerebral Digital Subtraction Angiography: A Study on Radiation Dose Reduction and Image Quality Assessment”

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