OPEN ACCESS

Scholars International Journal of Biochemistry
Abbreviated Key Title: Sch Int J Biochem
ISSN 2616-8650 (Print) | ISSN 2617-3476 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Review Article

Optimizing Neuroimaging Techniques for Enhanced Visualization of Intracranial Aneurysms

Ayesha Bintay Farooq[1*], Muhammad Awais Hamza[2], Izat Ijaz[1], Muhammad Umair Ishaq[1], Alishba Yasin[3]

[1]Department of Radiography and Imaging Technology, Allied Health Sciences, Government College University Faisalabad, Pakistan.
[2]School of Health and Life Sciences, Department of Podiatry and Radiography, Glasgow Caledonian University Scotland, UK.
[3]Department of Radiology, The University of Faisalabad, Pakistan

DOI: https://doi.org/10.36348/sijb.2024.v07i05.001 | **Received:** 21.07.2024 | **Accepted:** 25.08.2024 | **Published:** 30.08.2024

***Corresponding author:** Ayesha Bintay Farooq
Department of Radiography and Imaging Technology, Allied Health Sciences, Government College University Faisalabad, Pakistan

Abstract

Intracranial aneurysms, abnormal dilations of blood vessels in the brain, pose significant health risks, especially when ruptured, leading to conditions such as subarachnoid hemorrhage and stroke. The primary objective of this study is to evaluate the diagnostic accuracy of different computed tomography angiography (CTA) protocols for detecting intracranial aneurysms and to identify methods for optimizing scanning parameters to reduce radiation exposure while ensuring high image quality. Results from the analysis of various CTA protocols revealed that lowering tube voltages (80-120 kV) and milliampere seconds (mAs) effectively reduced radiation exposure without compromising the quality of images. Additionally, the use of advanced reconstruction algorithms, including deep learning techniques, significantly improved the visualization of small vascular structures, thereby enhancing diagnostic accuracy. These findings provide valuable insights for enhancing clinical practices in the fields of neurology and radiology.

Keywords: Neuroimaging, CT scan, Intracranial aneurysm, CTA.

INTRODUCTION

The Brain Aneurysm Foundation of the USA., 2022 describes an intracranial aneurysm can be similar to a delicate balloon or a weak spot on a tire's inner tube because it bulges within a brain artery, as illustrated in Figures 01 and 02. Aneurysms are categorized into either saccular or fusiform depending on their shape as detailed by Rayz and Cohen Gadol (2020), illustrated in Figures 03 and 04. Saccular aneurysms, also known as berry aneurysms, are bulges resembling pouches that develop from the wall of a blood vessel in the brain. In contrast, fusiform aneurysms, which are less common are enlargements that affect a short section of a blood vessel, causing the entire vessel diameter to increase (Xu *et al.*, 2019). The likelihood of a rupture is higher with this kind of aneurysm. If a rupture occurs, it could lead to a subarachnoid hemorrhage (SAH), causing blood to escape into the area between the skull and the brain potentially leading to a stroke, posing a threat to life (Pala *et al.*, 2019).

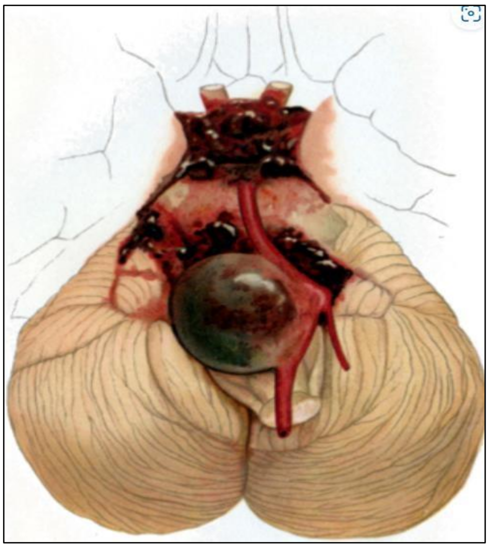

Figure 1: Depicts an aneurysm affecting the basilar artery and the vertebral arteries, with the image sourced from Wikipedia

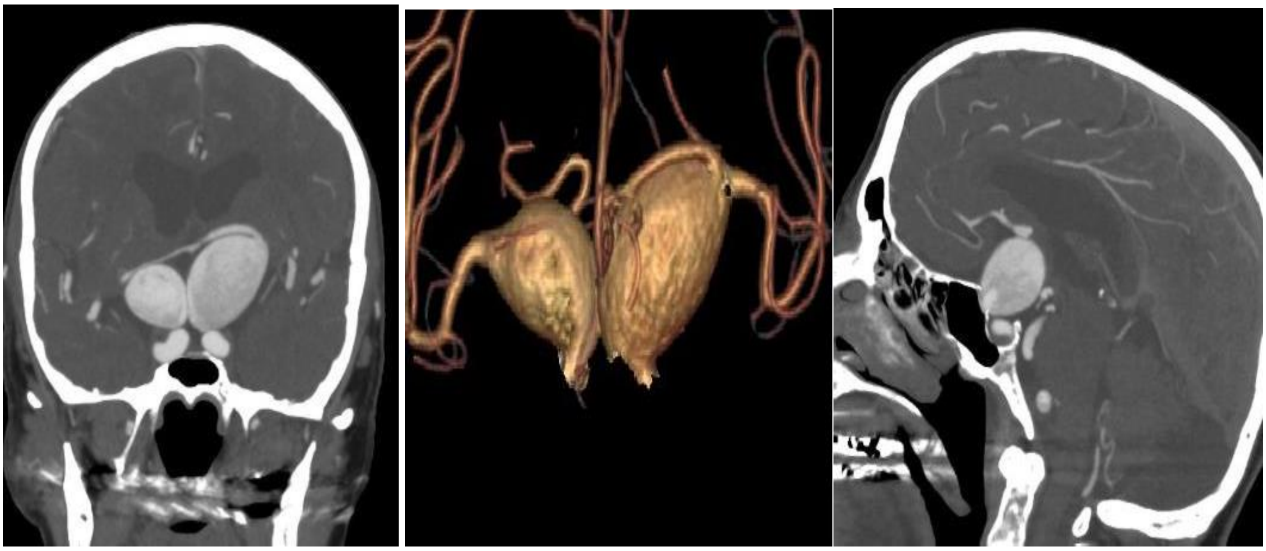

Figure 2: Shows a large giant aneurysm in the internal carotid artery on both sides, with the image sourced from Radiopedia

Figure 3: Saccular aneurysm (Images sourced from Brain aneurysm foundation, USA)

Figure 4: Fusiform Aneurysm (Images sourced from Brain aneurysm foundation, USA)

Sign and Symptoms

Ruptures typically occur unexpectedly, specific activities that quickly increase blood pressure like nose-blowing, sexual activity, defecation, intense physical exercise, and emotional outbursts can trigger it (Vlak *et al.*, 2014). Headache, a common reason for diagnostic imaging leading to the detection of unruptured intracranial aneurysms (UIAs), presents a challenge in diagnosis. It's often uncertain if the headache is directly caused by the aneurysm, especially when there's no subarachnoid hemorrhage (Tenny and Thorell., 2023). Several factors like aneurysmal characteristics, including size and location can influence symptomatology by potentially compressing adjacent structures (Tawk *et al.*, 2021).

Causes and Risk Factors

Generally, brain aneurysms progress slowly as a result of factors affecting the flexibility of the blood vessel wall (Toth and Cerejo., 2018). The area of the blood vessel wall that is impacted becomes less flexible, which can happen because of the normal aging process, higher pressure from hypertension, or harm from smoking or inflammation (Morel Bijlenga and Kwak, 2022). Sometimes, severe head injuries or infections may also contribute to the formation of aneurysms, although this is uncommon (American Brain Foundation, 2024). Moreover, aneurysms also may occur due to genetic conditions such as Ehlers-Danlos syndrome which causes weakened connective tissue and in turn, weakened blood vessel walls (Gui *et al.,* 2016).

Two significant risk factors are smoking and hypertension, both of which are modifiable (Slettebø and Karic Sorteberg, 2020). Genetic tendencies, growing older (beyond 40) gender (with women being more vulnerable), and particular racial backgrounds also contribute to an individual's susceptibility (Wang *et al.*, 2018). Certain factors such as substance abuse, excessive alcohol consumption, infections, and severe head traumas can also elevate the likelihood of complications, especially when it comes to lifestyle (Ghodeshwar Dube and hobragade, 2023). Additionally, Individuals who have elevated blood pressure are more likely to develop brain aneurysms, with women facing a higher risk than men do (Cras *et al.,* 2020; Zuurbier *et al.,* 2022).

Epidemiology of Intracranial Aneurysm

Approximately, 2.8% of adults around the world are believed to have aneurysms, impacting approximately 2% to 5% of the adult population globally. The majority of patients in this group are typically aged between 35 and 60 (Toth and Cerejo, 2018; Thompson *et al.,* 2015). The incidence ranges from 2.0 to 22.5 cases per 100,000 people globally, with the highest rates observed in Finland and Japan (Ikawa *et al.,* 2019). In women, the occurrence of aneurysms is higher than in men, with a ratio of 3 to 2. However, before the age of 40, both men and women are affected at equal rates (Brain Aneurysm Foundation, 2023). Nonetheless, 500,000 people worldwide die each year due to brain aneurysms with half of these individuals being under 50 years old (Brain Aneurysm Foundation, 2023; Rizvi, 2021).

DISCUSSION

According to NICE guidelines (NG228), It's crucial to make a prompt request for a contrast Computed Tomography (CT) head scan referral for people showing signs of subarachnoid hemorrhage. The peak accuracy of a CT head scan occurs within six hours after the symptoms first appear. Additionally, if blood is detected in the subarachnoid space, immediate head CT angiography is required for individuals diagnosed with subarachnoid hemorrhage to verify the existence of an aneurysm and signs of aneurysm rupture (NICE, 2022).

Scanning Protocol

Brain Computed Tomography Angiography (CTA), using helical technology on multi-detector row scanners, is the primary CT imaging protocol employed for diagnosing intracranial aneurysms (Hacein-Bey and Provenzale, 2014). Demchuk *et al.,* (2016) proposed that to accurately pinpoint and describe aneurysms a reliable method should include both scans: without contrast and scans, and with contrast enhancement. Ospel *et al.,* (2021) further endorse this approach, suggesting that non-contrast CT (NCCT) combined with single-phase CTA is the most straightforward and potentially quickest method, offering high reliability in evaluating lesion extent, particularly among experienced professionals. The first non-contrast CT (NCCT) scan is crucial for obtaining information about the baseline anatomy, detecting acute hemorrhage, and assessing potential calcifications within the arterial wall, which could indicate the risk of aneurysm rupture (Abdalkader *et al*., 2023). After the non-contrast scan, CT angiography also known as CTA is performed to image the blood vessels in the brain and detect any aneurysms, thereby enhancing the detection rate of ruptured cerebral aneurysms in situations where timely diagnosis is crucial (Yoon *et al.,* 2016).

Scanning parameters

When diagnosing patients, considering the optimization of protocols is crucial as it entails the fine-tuning of protocol parameters to achieve good image quality for the specific clinical imaging task while maintaining a radiation dose that is clinically justified (Chen *et al.,* 2017). Raman *et al.,* (2014) emphasized the importance of tuning or optimizing eight CT scan parameters for CT brain angiography to decrease radiation exposure for patients. These parameters encompass detector configuration, mAs, kVp, reconstruction algorithm, patient positioning, scan range, reconstructed slice thickness, and pitch. Although there's always a balance between image quality or noise and patient radiation dose, fine-tuning these settings can lead to acquiring images of patients while using lower doses and still maintaining diagnostic image quality (Mayo-Smith *et al.,* 2014).

Detectors

In comparison, when it comes to CTA, solid-state crystal detectors, also known as scintillation detectors are typically considered a good choice than xenon gas detectors (Shefer *et al.,* 2014; Ljungberg and Pretorius., 2016). Yanagida (2018) clarifies that solid-state crystal detectors offer quicker acquisition times due to their higher absorption coefficients, allowing them to ideally absorb 100% of photons, whereas Xenon gas detectors usually absorb around 60% to 87% of photons. This leads to enhanced spatial resolution, increased sensitivity, and superior image quality for imaging small vascular structures, such as those encountered in cerebral angiography, as a result of more effective detection of incoming photons.

kVp and mAs

Recently, many research papers have explored ways to adjust tube potential and mAs settings to minimise radiation exposure levels in brain CTA brain angiography (Luo *et al.*, 2015; Chen *et al.*, 2017; Sollmann *et al.*, 2019). CT brain angiography protocol usually uses a range of 200 to 250 effective milliampere seconds (mAs) with tube voltages typically set between 80 and 120 kilovolts (kV) (Imai *et al.*, 2014). In the study conducted by Imai *et al.*, 2014, It is claimed that utilizing the power level (measured in milliampere seconds) is beneficial, for achieving images in both standard and 3D scans in accordance, with the manufacturer's recommendations.; recommends a setting of 252 mAs as an example.

However, Tang et al. found that cerebral CTA with a low tube voltage of 100 kV greatly improves the identification of aneurysms intracranial, as a standard scanning approach. Nevertheless, most of these investigations have shown the ability of axial CT images to detect aneurysms, whereas limited research has explored this capability in both axial and 3D CTA scans. In addition, there is no definitive quantitative descriptor that accurately describes the quality of 3D CTA images.

Image reconstruction

Kamalian *et al*., (2016) have highlighted the advancements in reconstruction algorithms showing improvement in spatial resolution, noise reduction, and potential for reducing radiation exposure without compromising diagnostic precision. In a recent investigation conducted by Otgonbaatar *et al*., (2021), it was observed that the use of deep learning methods significantly enhances the clarity of brain CTA images, as demonstrated by both objective metrics and subjective evaluations. When compared to filtered back projection (FBP) and hybrid iterative reconstruction (IR) methods, the deep learning reconstruction algorithm shows benefits especially, in its ability to accurately represent small blood vessels as shown in Figure 05.

However, it is important to acknowledge this study was a retrospective study that only assessed a relatively small number of patients.

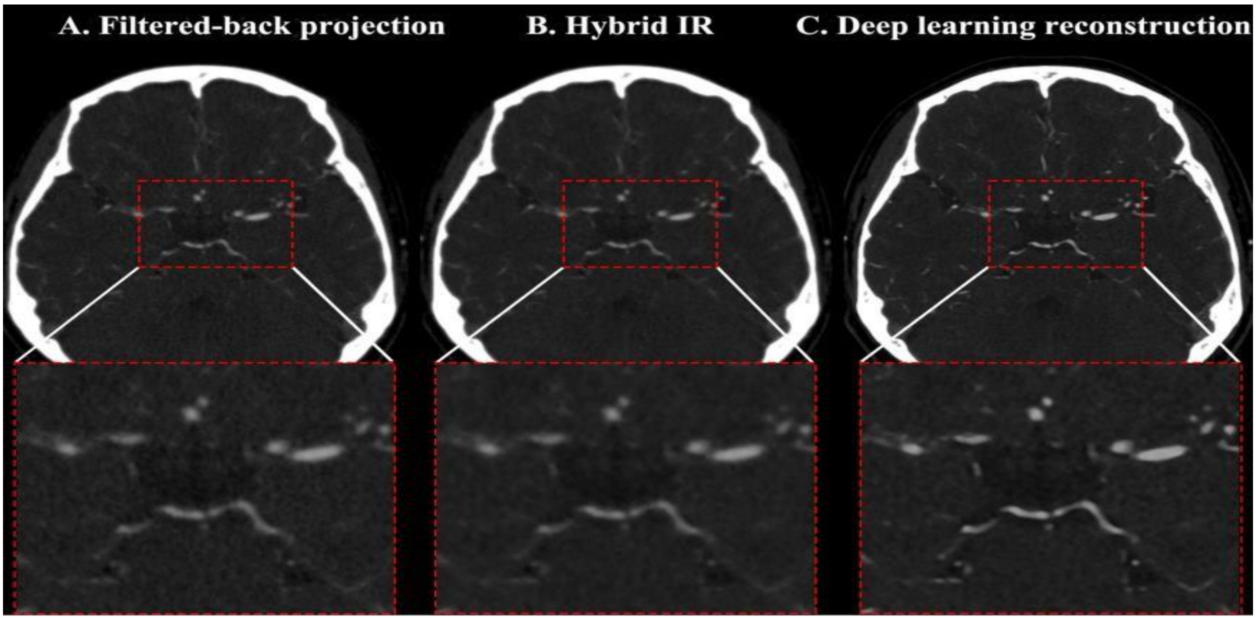

Figure 5: Presents axial brain CTA images aimed at visualizing intracranial vessels. It contrasts brain CTA images generated through filtered-back projection (A), hybrid iterative reconstruction (IR) (B), and deep learning reconstruction (C) methods in terms of visualizing blood vessels. The deep learning reconstructions (C) showed delineated vessel walls with minimal noise in the images and sharp vessels, contrasting with the hybrid iterative (B) and filtered-back projection (A) algorithms (Image sourced from Otgonbaatar *et al*., 2021)

Patient positioning and scan range

Improperly positioning and centering patients may result in image distortion and unwanted artifacts that can compromise detection of incidental pathologies besides exposing patients to higher radiation doses than needed (Ebrahimian *et al.*, 2021). The usual and most common approach for conducting CTTA procedures usually requires positioning the patient lying on supine with arms positioned alongside the body, head entering the gantry first (Takeyama *et al.*, 2014). Gang *et al*., (2020) introduced an innovative idea involving the use of AI technology, for positioning and centering in CT imaging which has the capability to lower radiation exposure, simplify the imaging process and enhance the quality of images. However, this innovative idea was tested on a CT scanner produced by a specific manufacturer. Hence, further research is required to explore how well AI positioning techniques can be applied across CT scanners.

The typical scanning area for a brain CTA usually includes the brain and its major blood vessels that supply blood to it, including the internal carotid arteries, vertebral arteries, and the Circle of Willis (Hu *et al.*, 2021). The range for scanning usually goes from the top of the head or vertex to either the bottom of the skull or the neck, depending on the clinical indication and the specific imaging protocol employed (Tang *et al.*, 2015). On the contrary, some research points out a scanning area that extends from the arch of the aorta to the top point of the head, as demonstrated in Figure 06 (Sugrue *et al.*, 2018), potentially leading to radiation exposure for patients unless there is a clinical need.

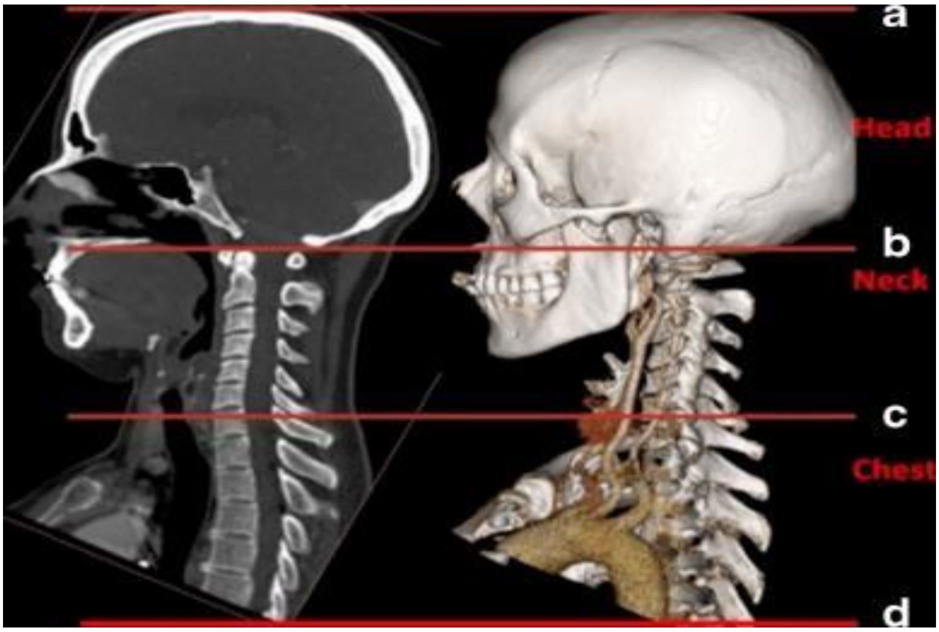

Figure 6: The typical field of view for conventional CTA Brain ranges from the aortic arch to the top of the skull skull to the tip of the odontoid peg, while the neck region (B) extends from the tip of the odontoid peg to the C6–7-disc spaces. The chest region (C) encompasses the C6 to C7 disc spaces down to the aortic arch (D)
(Image Adopted from Sugrue *et al*., 2019)

Collimation, slice thickness, and pitch

In cerebral angiography studies, a variety of slice thicknesses and scanning pitches have been noted, highlighting the diversity of protocol approaches used in brain CTA imaging procedures. Chen *et al.*, 2017 employed a collimation of 64×2×0.6 mm with a pitch of 1.2, indicating one approach to image acquisition. Luo *et al.*, 2015, on the other hand, utilised a collimation of 64×0.6 mm and a pitch of 1.5, coupled with reconstructed images having a 0.75-mm section thickness. Interestingly, Cornelissen *et al.*, 2015 recommended thin slices, typically 1 mm or less, with an overlap of 30%, which aids in optimal post-processing techniques such as multiplanar reformation (MPR). Moreover, in Study by Kim *et al.*, 2020, a collimation of 64×0.625 mm and a pitch factor of 0.516 were employed, showcasing another set of parameters used in clinical practice. Overall, these studies emphasised the differences in the thickness of slices and pitch values showing a preference for thinner slices and a wide range of pitch variations. The choice of these parameters is determined by factors like the type of scanner used, the needs of the clinical outcome and the desired post processing functionalities.

Instrumentation

In brain CTA, it is crucial to utilise head immobilisation straps and radiolucent pads to ensure the safety of patients and obtain high-quality images effectively (Kamalian, Lev and Gupta., 2016). Head immobilisation straps are used to keep the patients head in stationary position while undergoing for scan a scan which is designed to reduce motion artifacts and ensuring precise image acquisition (Contesini *et al.*, 2017; Nardi *et al.*, 2017). Likewise, radiolucent pads are placed beneath the patient's head to provide support and comfort during the procedure (Haranhalli *et al.*, 2017). These pads are made of such materials that allow X-rays to pass through without blocking the imaging area or affecting the image quality (Gui *et al.*, 2016).

Choosing the size of cannula for injecting contrast dye during brain angiography is also another important factor to think about. Ideally, a cannula is thin and flexible tube that is placed into a vein to help with administering a contrast agent while conducting the scan (Kidoh *et al.*, 2015). Choosing the IV cannula for brain angiography involves considering factors such as the patients age, the size of the vein and how well the contrast agent flows and its viscosity (Marshal *et al.*, 2019). Although many authors often highlights use for a 20 gauge cannula (pink), as depicted in Figure 07 in their primary studies (Luo *et al.*, 2015; Cho *et al.*, 2015), there are no guidelines or legal obligations that one must follow.

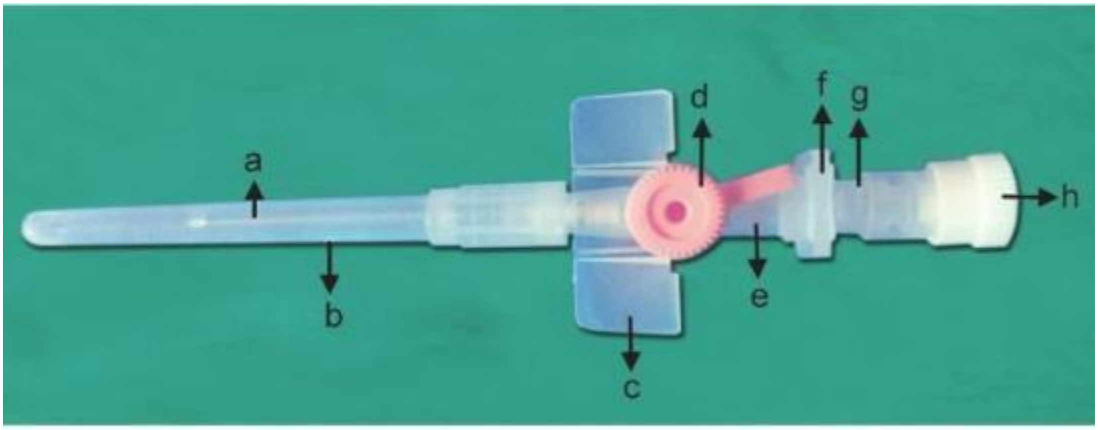

Figure 7: Illustrates peripheral Venous cannulation: 20-gauge cannula, displaying: a) Catheter over needle b) protective covering c) catheter wings d) injection port e) Luer connector f) needle grip g) Flash chamber h) Luer lock plug (Image sourced from Kothari and Sharma, 2015)

Administering contrast using a high flow rate through an automatic pressure injector has become a standard procedure nowadays (Jones and Hoggs, 2014). In CT brain angiography, these sophisticated tools shown in Figures 08 and 09 are used to deliver the contrast agent which guarantees consistent image quality and reducing contrast-related complications by delivering accurate volumes at controlled rates (Kaluski *et al.*, 2016). Al-Jamal and Al-Adam (2019) argue that using an automatic injector is crucial for administering contrast medium in all Contrast enhanced CTAs, including brain angiography.

Moreover, the systematic review and meta-analysis conducted by Minsinger *et al*., (2015) revealed that the use of automatic contrast injectors in angiography significantly reduces the amount of contrast given to patients and lowers the risk of contrast-induced nephropathy (CIN). In a study, by Dostal *et al.*, (2023) conducted a review to assess the dependability of auto-injectors, focusing on malfunction and presenting an overview of the failure rate. Their findings revealed that auto-injectors are generally reliable devices, supporting the implementation of training programs for healthcare professionals and patients to optimize their use and maintenance. Nonetheless, there have been questions expressed about potential for contrast extravasation and allergic reactions which highlighted the significance of selecting patients, closely monitoring patients and adherence to injection protocols to minimise adverse events.

Figure 8: Displays the ACIST EmpowerCTA Dual Syringe CT Contrast Injector (Image sourced from GE Healthcare, vendor)

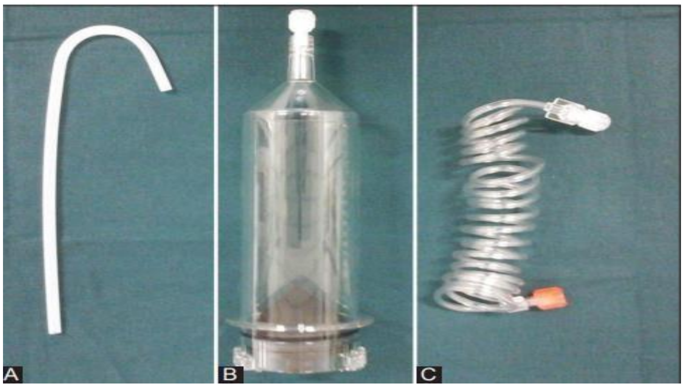

Figure 9 (A-C): Demonstrates the functional elements of syringes in a pressure injector system, proceeding from left to right: The syringe can be filled using either a J-tube or spike filling method. (B) Pressure syringes, which are both latex-free and transparent, can be pre-filled or loaded manually. (C) Pressure tubing and connectors guarantee precise transmission of the chosen amount, pressure, flow, and contrast rate between the injector system and the patient, particularly during simultaneous scanning and table movement
(Image adapted from Indrajitet *et al*., 2015)

Contrast media and diagnostic performance compared to another modality

For brain CTA, it is essential to observe both the designated slice of interest and the carotid artery in order to establish the threshold of 100 Hounsfield Units (HU) (Zhou *et al.*, 2014). Mehta *et al*., (2023) conducted a study to investigate different concentration of CT contrast agents for the detection of aneurysms. Their research discovered that Isovue 370 provides the highest radiopacity when measured in HU and yields the most precise measurements for aneurysms. Nevertheless, the measurements of aneurysms using Isovue 300 in evaluations may not accurately reflect their true size. Remarkably, Both Visipaque 320 and Omnipaque 300 when given in their full concentration demonstrated comparable HUs and provide benefits for people dealing with long term kidney or heart issues. The typical procedure for brain CTA involves administering the injection of around 50-75 milliliters of iodinated contrast at a speed of 4.5 to 5 milliliters per second which is followed by a 100 milliliter saline flush as advised by Radiopedia's latest guidelines from 2023. However, Tamura *et al.*, (2014) explored the varying impacts of contrast volume and saline flush and observed promising outcomes in image quality, as depicted in Figure 10. Their finding indicated that employing only 50 mL of contrast material alongside a 20-mL saline flush yielded attenuation and uniformity of the contrast column similar to that achieved with 100 mL of contrast material in 16-MDCT angiography of the brain. The variation not only saved the cost but also lowered the risk of developing contrast-induced nephropathy. Luo *et al.*, (2014) further validated this minimal contrast technique. Their research illustrated that achieving quality images in cerebral CTA is possible with a lower radiation dose using just 30 ml of contrast agent.

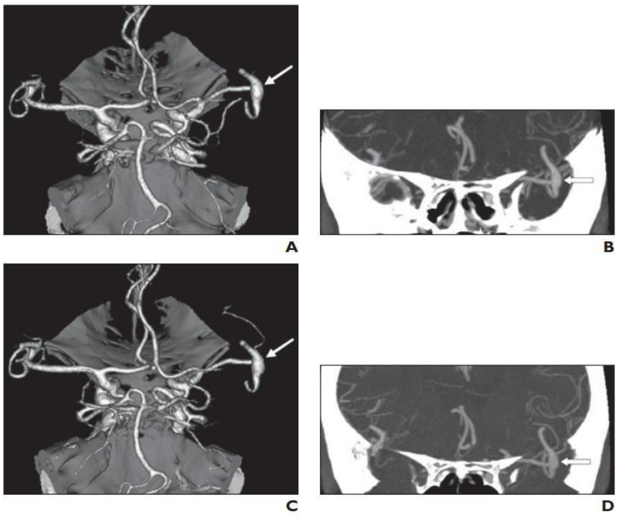

Figure 10: Illustrates a scenario concerning a 73-year-old male diagnosed with an aneurysm in the right middle cerebral artery, categorized within group A (50-mL contrast protocol). In panels A and B, images obtained from scans performed before the study period showcase volume-rendered CTA (A) and maximum intensity-projection (MIP) (B) using a 100-mL contrast protocol, presenting a distinct view of intracranial arteries and highlighting the aneurysm in the right middle cerebral artery (marked by an arrow).In panels C and D, volume-rendered CTA (C) and MIP (D) images of the identical patient during the study period using a 50-mL contrast protocol demonstrate sufficient visualization of all intracranial arteries and the aneurysm (arrow), maintaining image quality similar to that achieved with the 100-mL protocol (Image sourced from Tamura *et al*., (2014)

Abbasi *et al*., (2023) emphasised the importance of using a contrast agent pointing out that detecting an aneurysm would be more challenging without it, as illustrated in Figure 11. Without contrast in blood vessels, an aneurysm would have a density that closely resembles the surrounding tissue making it harder to differentiate.

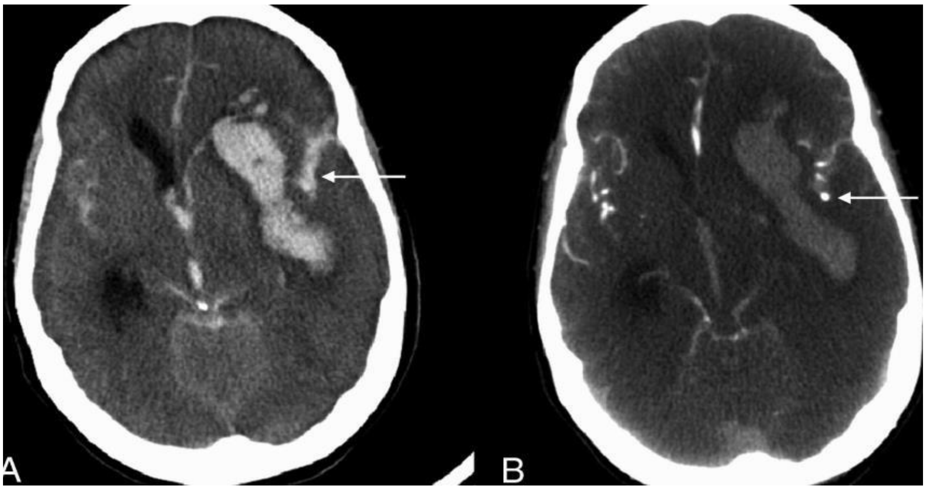

Figure 11: Illustrates CT Angiography used to distinguish between intracerebral and intra-sylvian hematoma in individuals with ruptured middle cerebral artery aneurysms, with A) representing a non-contrast CT head, and B) showing a contrast-enhanced CT head
(Image sourced from Abbasi *et al*., 2023).

Yang *et al*., (2017) carried out a study that compared contrast enhanced brain CTA to subtraction angiography (DSA), considered as the reference standard. The result demonstrated the excellent sensitivity and specificity of contrast-enhanced brain CTA. Reader 1 correctly identified 97.1% of cases, while Reader 2 identified 97.4%, with specificities of 98.5% and 99.1%, respectively, as depicted in Table 1.

Additionally, when evaluating aneurysms both readers showed high accuracy, particularly, with aneurysms over 3 mm, in size or those were ruptured. However, this study found that smaller or non-ruptured aneurysms showed poor sensitivity.

Table 1: The sensitivity and specificity of contrast-enhanced CT brain angiography as reported by Yang *et al*., for both per patient and per aneurysm basis, as observed by Reader 1 and Reader 2

	Sensitivity	Specificity
Per Patient (Reader 1)	97.1	98.5
Per Patient (Reader 2)	97.4	99.1
Per aneurysm (Reader 1)	95.2	96.6
Per aneurysm (Reader 2)	95.4	97.0

In the meta-analysis, Chen *et al*., 2018 analyzed ten primary papers to compare the use of contrast-enhanced CTA versus Magnetic Resonance Angiography (MRA) in diagnosing intracranial aneurysms. It is found that CTA showed a pooled sensitivity of 84% and specificity of 85%, while MRA demonstrated a pooled sensitivity of 80% and specificity of 87% which is depicted in Table 2. The diagnostic performance was almost identical, in both imaging methods.

Table 2: The sensitivity and specificity of computed tomography angiography (CTA) and magnetic resonance angiography (MRA) for diagnosing intracranial aneurysms, as reported by Chen et al.,

Diagnostic Parameter	CTA	MRA
Sensitivity	84	80
Specificity	85	87

Limitation

On the downside, there are limitations when it comes to using CT scans to diagnose aneurysms. Using Brain CTA may not always be effective for Identifying aneurysms, particularly those less than 3 mm in size, and could lead to missed detection (Chung *et al.,* 2022). Aneurysms of this kind could be located in the vicinity of the carotid siphon, near the dense skull base, and, along the cavernous sinus, possibly due to the presence of calcified and non-calcified atherosclerotic plaque. The reason for this is that ionising radiation is absorbed equally by calcium and iodinated contrast agents (Maupu, Lebas, and Boulaftal, 2022). In response to this challenge, a novel technique called match mask bone elimination (MMBE) has been created to get rid of signals originating from bones. However, it involves a prolonged exposure to ionising radiation and is affected by even a minimal patient movement (An *et al.,* 2023). Likewise, after undergoing treatment procedures such, as clipping or endovascular coil embolisation, evaluating the condition of blood vessels within the skull presents difficulties because of beam hardening and photon starvation artifacts that arise from implants, as depicted in Figure 12 (Belavadi *et al.,* 2021).

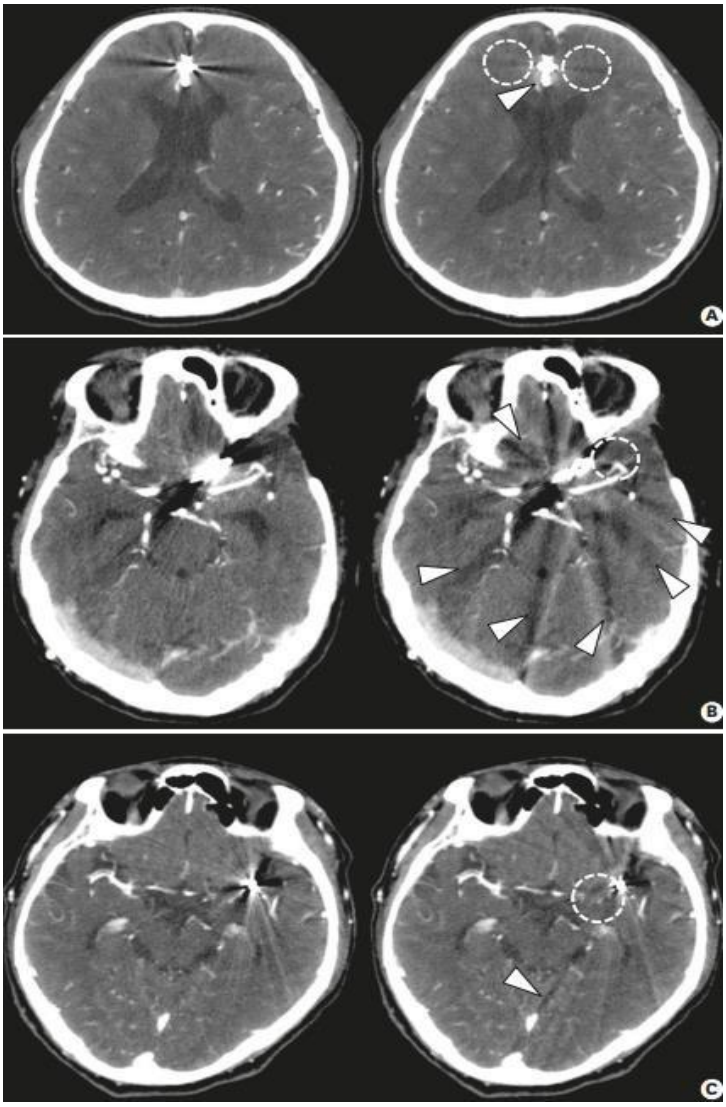

Figure 12: Presents images contrasting Non-Orthopedic Metal Artifact Reduction (Non-O-MAR) on the left with Orthopedic Metal Artifact Reduction (O-MAR) on the right, using representative cases. (A) Displays a surgical clip situated at the junction of the right A2/3 in a male patient aged 71. The O-MAR image exhibits enhanced reduction in streak artifacts (marked by dashed circles), although there is a slight decrease in vessel depiction clarity (indicated by the arrowhead).(B) Depicts a 68-year-old male patient who had undergone surgical clipping for an anterior communicating artery aneurysm. In the O-MAR image, there are several bands of worsened streak artifacts (indicated by arrowheads), alongside an area where streak artifacts have improved (marked by a dashed circle). (C) Illustrates a 73-year-old male patient who had undergone coil embolization for an aneurysm located at the bifurcation of the left middle cerebral artery. In the O-MAR image, there is a slight enhancement in streak artifact reduction (especially in the area marked by the dashed circle), yet with a localized exacerbation of streak artifact (indicated by the arrowhead). O-MAR stands for Orthopedic Metal Artifact Reduction
(Image sourced from Sunwoo *et al*., 2018)

Additionally, administering iodinated contrast agents during a CTA procedure may pose risks for people with kidney issues or allergies to iodine, constraining its applicability in specific patient groups (Davenport, Cohan, and Ellis, 2015). Nevertheless, it's important to recognise that the use of non-ionic low osmolar contrast media has significantly reduced the incidence of adverse reactions caused by contrast agents (Bottinor *et al.*, 2014). Likewise, although the amount of radiation utilised in modern imaging technologies is lower compared to older methods, there are still inherent risks involved (Power *et al.*, 2016). Based on the guidelines provided by the International Commission on Radiological Protection in their 2007 publication, it is noted that the eye lens is highly susceptible to radiation exposure. Particularly in young patients or those undergoing repeated imaging studies, these risks are more evident (Browe and Rehani, 2021). Therefore, when CTA brain appeared as a strong modality for diagnosing intracranial aneurysm, it is also worth noting that sophisticated protocol optimisation, alternative diagnosis are required for comprehensive evaluation.

Implication of CT scan diagnosis for intracranial aneurysms

As a master's level radiography student, I understand the implications of CT scan diagnosis for intracranial aneurysms on patient care and outcomes. As a healthcare professional, I have an important role in this process where I hold the potential to assess and educate people about factors so that they can change lifestyles to reduce the chances of developing an aneurysm. Studies have regularly emphasized the relationship between lifestyle decisions and the likelihood of developing aneurysms. Current smoking, hypertension, and a family history of stroke increase the risk of unruptured intracranial aneurysms, with smoking and hypertension having an additive effect, whereas hypercholesterolemia and regular physical exercise decrease this risk (Vlak *et al.*, 2014). Therefore, clinicians should inform and discuss these modifiable risk factors with patients, enhancing not only patient awareness but also paving the way for personalized preventive strategies tailored to each patient's needs and risk profile. In acute medical care, it's essential to diagnose and treat suspected aneurysms as quickly as possible to enhance the chances of positive patient outcomes (Choudhry *et al.*, 2021). In 2023, NHS England partnered with The Royal College of Radiologists and The Society of Radiographers to set up guidelines for turnaround time (TAT), with a maximum TAT of 12 hours for urgent inpatients to ensure timely diagnostic imaging and medical assessment (NHS England, 2023). However, recognising the urgency for certain patient populations, additional conditions, such as a TAT of less than 4 hours for emergency department (ED) patients or acutely unwell hospital patients should be imposed. In cases where an intracranial aneurysm is suspected, policymakers should review current guideline and should minimize the turnaround time (TAT) from less than 4 hours to ensure implementation of treatments, thereby reducing the risk of aneurysm rupture and associated complications. Similarly, one promising area of future exploration involves the development of a new type of contrast agent known as CT nano-contrast agent (Jiang *et al.*, 2022). Metallic inorganic nanoparticles (NPs) containing high atomic numbers and significant X-ray attenuation capabilities display promising prospects for precise bio imaging purposes as CT contrast agents designed to approach the ideal characteristics of CT contrast with minimal associated risks (Lai *et al.*, 2024). This novel contrast agent has the power to transform current CT imaging with its contrast enhancement capabilities while mitigating the adverse effects commonly associated with traditional contrast agents. Studies have shown that using nano contrast agents can superiorly improve the visibility of structures and abnormal features, thereby improving diagnostic accuracy and clinical decision-making (Han *et al.*, 2019). However, I recommend for conducting comprehensive research on the safety and effectiveness of this innovation because some studies have reported that metallic nanoparticles can catalyse the generation of free radicals which causes further indirect damage in body (García *et al.*, 2023). As recommended, in the continuous pursuit of refining diagnostic imaging, the development of sophisticated algorithms targeted at mitigating imaging artifacts represents a critical area of research aimed at optimising image quality and diagnostic accuracy. By focusing on eradicating common challenges such as streak artifacts and motion artifacts, researchers should strive to create images that closely resemble the ideal images, making it easier to provide precise diagnoses. These algorithms use advanced methods such as machine learning and deep learning to detect and fix artifacts in real time, thereby enhancing the clarity and fidelity of diagnostic images. Furthermore, by minimising the presence of artifacts, not only can the likelihood of misinterpretation be reduced, but also diagnostic errors can be minimised (Abimanyi-Ochom *et al.*, 2019), ultimately improving patient care outcomes. Through continued development and refinement of imaging artifact correction algorithms, the medical community can expect to enter a new era of diagnostic imaging marked by improved image clarity, accuracy, safety in diagnoses and better patient care.

CONCLUSION

In conclusion, the advancements in CT imaging technology and protocols have been playing a significant role in detecting and treating aneurysms at an early stage, ultimately leading to improved patient outcomes and quality of care in neuroimaging. The comprehensive imaging protocol involving both scans without contrast and with contrast offers crucial insights for identifying and understanding intracranial aneurysms. While CT imaging, particularly CT angiography, plays a pivotal role in the diagnosis of intracranial aneurysms due to its rapid acquisition, excellent spatial resolution, and high sensitivity in detecting acute hemorrhagic events, recognising the constraints and potential dangers linked with using contrast agents and exposure to radiation is crucial. Therefore, a judicious and personalised approach to imaging, coupled with patient education on modifiable risk factors is crucial for the effective screening, diagnosis, and management of intracranial aneurysms. Continued advancements in imaging technologies like investigating novel contrast agents and refining artifact correction algorithms hold the potential for improving further enhancing diagnostic accuracy, patient safety, and overall healthcare outcomes in the field of neuroimaging.

ABBREVIATIONS

ICH - Intracerebral Hemorrhage SAH - Subarachnoid Hemorrhage
CTA - CT Angiography
ICM - Iodinated Contrast Media
ICRP - International Commission on Radiological Protection NCCT – Non contrast Computerised Tomography
ED - Emergency Department HU - Hounsfield Units
NICE - National Institute for Health and Care Excellence TAT - Turnaround Time
NHS - National Health Service
O-MAR - Metal Artifact Reduction for Orthopedic Implants UIAs – Unruptured Intracranial Aneurysms

BIBLIOGRAPHY

- Abdalkader, M., Siegler, J.E., Lee, J.S., Yaghi, S., Qiu, Z., Huo, X., Miao, Z., Campbell, B.C.V. and Nguyen, T.N. (2023) Neuroimaging of Acute Ischemic Stroke: Multimodal Imaging Approach for Acute Endovascular Therapy Korean Stroke Society, pp. 55.
- Abimanyi-Ochom, J., Bohingamu Mudiyanselage, S., Catchpool, M., Firipis, M., Wanni Arachchige Dona, S. and Watts, J.J. (2019) Strategies to reduce diagnostic errors: a systematic review Springer Science and Business Media LLC.
- ACIST EmpowerCTA Dual Head CT Injector with EDA - Ceiling Mount, Computed Tomography (CT) | GE HealthCare Service Shop USA (2023). https://dev-services.gehealthcare.com/gehcstorefront/p/E8005JE.
- Al-Jamal, A., Al-Adam, R. and Qawasma, R. Design and Development of a Full Automated Contrast Injector Device for CT-Scan protocol: improved vascular enhancement with a reduced volume of contrast medium and radiation dose Springer Science and Business Media LLC, pp. 1421.
- Brain Aneurysm Foundation (2022): Brain Aneurysm Basics https://www.bafound.org/about-brain-aneurysms/brain-aneurysm-basics/.
- Brain Aneurysm Foundation (2024): Causes/Risk factors https://www.bafound.org/about-brain-aneurysms/brain-aneurysm-basics/risk-factors/.
- Brain Aneurysm Foundation (2024): Statistics and Facts https://www.bafound.org/statistics-and-facts/.
- Brower, C. and Rehani, M.M. (2021) Radiation risk issues in recurrent imaging Oxford University Press (OUP).
- Cho, E., Chung, T., Ahn, S.J., Chong, K., Baek, J.H. and Suh, S.H. (2014) Cerebral computed tomography angiography using a 70 kVp.
- Choudhry, A., Murray, D., Corr, P., Nolan, D., Coffey, D., Macnally, S., O'hare, A., Power, S., Crockett, M., Thornton, J., Rawluk, D., Brennan, P. and Javadpour, M. (2021) Timing of treatment of aneurysmal subarachnoid haemorrhage: are the goals set in international guidelines achievable? Springer Science and Business Media LLC, pp. 401.
- Contesini, M., Guberti, M., Saccani, R., Braglia, L., Iotti, C., Botti, A., Abbati, E. and Iemmi, M. (2017) Setup errors in patients with head-neck cancer (HNC), treated using the Intensity Modulated Radiation Therapy (IMRT) technique: how it influences the customised immobilisation systems, patient's pain and anxiety Springer Science and Business Media LLC.
- Cornelissen, S.A., Das, M. and Postma, A.A. (2015) CT Imaging of Intracranial Vessels Springer US, pp. 93.
- Cras, T.Y., Bos, D., Ikram, M.A., Vergouwen, M.D.I., Dippel, D.W.J., Voortman, T., Adams, H.H.H., Vernooij, M.W. and Roozenbeek, B. (2020) Determinants of the Presence and Size of Intracranial Aneurysms in the General Population Ovid Technologies (Wolters Kluwer Health), pp. 2103.
- Davenport, M.S., Cohan, R.H. and Ellis, J.H. (2015) Contrast Media Controversies in 2015: Imaging Patients With Renal Impairment or Risk of Contrast Reaction American Roentgen Ray Society, pp. 1174.
- Demchuk, A.M., Menon, B.K., Goyal, M., Program, C.S., Kidwell, C.S. and Olivot, J. (2024) Comparing Vessel Imaging Noncontrast Computed Tomography/Computed Tomographic Angiography Should Be the New Minimum Standard in Acute Disabling Stroke.
- Dostal, P., Taubel, J., Lorch, U., Aggarwal, V. and York, T. (2023). The Reliability of Auto-Injectors in Clinical Use: A Systematic Review Springer Science and Business Media LLC.
- Ebrahimian, S., Oliveira Bernardo, M., Alberto Moscatelli, A., Tapajos, J., Leitão Tapajós, L., Jamil Khoury, H., Babaei, R., Karimi Mobin, H., Mohseni, I., Arru, C., Carriero, A., Falaschi, Z., Pasche, A., Saba, L., Homayounieh, F., Bizzo, B.C., Vassileva, J. and Kalra, M.K. (2021) Investigating centering, scan length, and arm position impact on radiation dose across 4 countries from 4 continents during pandemic: Mitigating key radioprotection issues Elsevier BV, pp. 125.
- Fahrenhorst-Jones, T. and Abdrabou, A. (2018) 'CT

angiography of the cerebral arteries (technique),' Radiopaedia.org. https://doi.org/10.53347/rid-57590.

- García, A., Cámara, J.A., Boullosa, A.M., Gustà, M.F., Mondragón, L., Schwartz, S., Casals, E., Abasolo, I., Bastús, N.G. and Puntes, V. (2023) Nanoceria as Safe Contrast Agents for X-ray CT Imaging MDPI AG.
- Ghodeshwar, G.K., Dube, A. and Khobragade, D. (2023) Impact of Lifestyle Modifications on Cardiovascular Health: A Narrative Review Springer Science and Business Media LLC.
- Gui, X., Li, F., Wu, L. and Zheng, Y. (2016) Systemic Multiple Aneurysms Caused by Vascular Ehlers-Danlos Syndrome SAGE Publications, pp. 354.
- Gul, P., Çaglayan, F., Akgul, N., & Akgul, H. M. (2017). Comparison of radiopacity of different composite resins. Journal of conservative dentistry: JCD, 20(1), 17–20. https://doi.org/10.4103/0972-0707.209071
- Hacein-Bey, L. and Provenzale, J.M. (2011) Current Imaging Assessment and Treatment of Intracranial Aneurysms American Roentgen Ray Society, pp. 32.
- Hackett, A.M., Koester, S.W., Rhodenhiser, E.G., Scherschinski, L., Rulney, J.D., Naik, A., Nico, E., Eberle, A.T., Hartke, J.N., Fox, B.M., Winkler, E.A., Catapano, J.S. andLawton, M.T. (2023) A comprehensive assessment of self-reported symptoms among patients harboring an unruptured intracranial aneurysm Frontiers Media SA.
- Han, X., Xu, K., Taratula, O. and Farsad, K. (2021) Applications of nanoparticles in biomedical imaging Royal Society of Chemistry (RSC), pp. 799.
- Haranhalli, N., Zeberg, H., Lasala, P. and Altschul, D. (2017) Radiolucent Skull Clamps for Intra-Operative Imaging: A Technical Note Springer Science and Business Media LLC.
- Hu, B., Shi, Z., Lu, L., Miao, Z., Wang, H., Zhou, Z., Zhang, F., Wang, R., Luo, X., Xu, F. and Li, S. A deep-learning model for intracranial aneurysm detection on CT angiography images in China: a stepwise, multicentre, early-stage clinical validation study.
- ICRP (2007). ICRP Publication 103. The 2007 Recommendations of the International Commission on Radiological Protection https://www.icrp.org/publication.asp?id=ICRP%20Publication%20103.
- Ikawa, F., Hidaka, T., Yoshiyama, M., Ohba, H., Matsuda, S., Ozono, I., Iihara, K., Kinouchi, H., Nozaki, K., Kato, Y., Morita, A., Michihata, N., Yasunaga, H. and Kurisu, K. (2019) Characteristics of Cerebral Aneurysms in Japan Japan Neurosurgical Society, pp. 399 Imai, K., Ikeda, M., Kawaura, C., Aoyama, T., Enchi, Y. and Yamauchi, M. (2012) Dose reduction and image quality in CT angiography for cerebral aneurysm with various tube potentials and current settings Oxford University Press (OUP), pp. e673.
- Indrajit, I.K., Sivasankar, R., D′souza, J., Pant, R., Negi, R.S., Sahu, S. and Pi, H. (2015) Pressure injectors for radiologists: A review and what is new Georg Thieme Verlag KG, pp. 2.
- Jeong, H.W., Seo, J.H., Kim, S.T., Jung, C.K. and Suh, S. (2014) Clinical Practice Guideline for the Management of Intracranial Aneurysms Korean Society of Interventional Neuroradiology.
- Jiang, Z., Zhang, M., Li, P., Wang, Y. and Fu, Q. (2023) Nanomaterial-based CT contrast agents and their applications in image-guided therapy Ivyspring International Publisher, pp. 483.
- Jones, D.W., Hogg, P. and Seeram, E. Practical SPECT/CT in Nuclear Medicine.
- Kaluski, E., Moussa, I.D., Heuser, R.R., Kern, M.J., Weisz, G., Klapholz, M. and Gerula, C. (2009) Automated contrast injectors for angiography: Devices, methodology, and safety Wiley, pp. 459.
- Kamalian, S., Lev, M.H. and Gupta, R. (a) Computed tomography imaging and angiographyprinciples.
- Kidoh, M., Hirai, T., Oda, S., Utsunomiya, D., Kawano, T., Yano, S., Nakamura, H., Makino, K., Iryo, Y., Azuma, M., Hayashida, E., Nakaura, T. and Yamashita, Y. (2015) Can CT angiography reconstructed from CT perfusion source data on a 320-section volume CT scanner replace conventional CT angiography for the evaluation of intracranial arteries? Springer Science and Business Media LLC, pp. 353.
- Kim, J.H., Lee, K., Ha, S.W. and Suh, S.H. (2021) Prevalence of Unruptured Intracranial Aneurysms: A Single Center Experience Using 3T Brain MR Angiography Korean Society of Interventional Neuroradiology, pp. 117.
- Kothari, N. and Sharma, A. (2016) 'Venous cannulation: peripheral,' in Jaypee Brothers Medical Publishers (P) Ltd. eBooks, p. 235. https://doi.org/10.5005/jp/books/12634_19.
- Lai, J., Luo, Z., Chen, L. and Wu, Z. (2024) Advances in nanotechnology-based targeted-contrast agents for computed tomography and magnetic resonance SAGE Publications.
- Li, W., Wang, G., Zhang, D., Wang, Z., Yang, L. and Yang, H. (2018) Risk factors for ruptured intracranial aneurysms Scientific Scholar.
- Ljungberg, M., & Pretorius, P. H. (2016). SPECT/CT: an update on technological developments and clinical applications Oxford University Press (OUP).
- Luo, S., Zhang, L. J., Meinel, F. G., Zhou, C. S., Qi, L., Mcquiston, A. D., Schoepf, U. J., & Lu, G. M. (2014a). Low tube voltage and low contrast material volume cerebral CT angiography Springer Science and Business Media LLC, pp. 1677.
- Luo, S., Zhang, L. J., Meinel, F. G., Zhou, C. S., Qi, L., Mcquiston, A.D., Schoepf, U. J., & Lu, G. M.

(2014b) Low tube voltage and low contrast material volume cerebral CT angiography Springer Science and Business Media LLC, pp. 1677.

- Luo, S., Zhang, L.J., Meinel, F.G., Zhou, C.S., Qi, L., Mcquiston, A.D., Schoepf, U.J. and Lu, G.M. (2014c) Low tube voltage and low contrast material volume cerebral CT angiography Springer Science and Business Media LLC, pp. 1677.
- Luo, S., Zhang, L.J., Meinel, F.G., Zhou, C.S., Qi, L., Mcquiston, A.D., Schoepf, U.J. and Lu, G.M. (2014d) Low tube voltage and low contrast material volume cerebral CT angiography Springer Science and Business Media LLC, pp. 1677.
- Marshall, T., Chen, N. M., Nguyen, E., Slattery, D. E., & Zitek, T. (2019). Rethinking Intravenous Catheter Size and Location for Computed Tomography Brain Angiography. The western journal of emergency medicine, 20(2), 244–249. https://doi.org/10.5811/westjem.2018.11.40930
- Mayo-Smith, W.W., Hara, A.K., Mahesh, M., Sahani, D.V. and Pavlicek, W. (2014) How I Do It: Managing Radiation Dose in CT Radiological Society of North America (RSNA), pp. 657.
- Mehta, A., Roa, J.A., Cannavale, K., Sur, S. and Singh, I.P. (2023) Differences in radiopacity among CT contrast agents and concentrations: A quantitative study Wiley, pp. 909.
- Minsinger, K.D., Kassis, H.M., Block, C.A., Sidhu, M. and Brown, J.R. (2016) Meta- Analysis of the Effect of Automated Contrast Injection Devices Versus Manual Injection and Contrast Volume on Risk of Contrast-Induced Nephropathy Elsevier BV, pp. 49.
- Morel, S., Bijlenga, P. and Kwak, B.R. (2021) Intracranial aneurysm wall (in)stability– current state of knowledge and clinical perspectives Springer Science and Business Media LLC, pp. 1233.
- Nardi, C., Taliani, G., Castellani, A., De Falco, L., Selvi, V. and Calistri, L. (2017) Repetition of examination due to motion artifacts in horizontal cone beam CT: Comparison among three different kinds of head support Medknow.
- NHS England: (2023) Diagnostic imaging reporting turnaround times. Developed in consultation with and supported by The Royal College of Radiologists and The Society of Radiographers https://www.england.nhs.uk/long-read/diagnostic-imaging- reporting-turnaround-times/.
- NICE (2022) Overview | Subarachnoid haemorrhage caused by a ruptured aneurysm: diagnosis and management | Guidance | NICE. https://www.nice.org.uk/guidance/ng228.
- Ospel, J.M., Volny, O., Qiu, W., Najm, M., Hafeez, M., Abdalrahman, S., Fainardi, E., Rubiera, M., Khaw, A., Shankar, J.J., Hill, M.D., Almekhlafi, M.A., Demchuk, A.M., Goyal, M. and Menon, B.K. (2021) Impact of Multiphase Computed Tomography Angiography for Endovascular Treatment Decision-Making on Outcomes in Patients with Acute Ischemic Stroke Korean Stroke Society, pp. 377.
- Otgonbaatar, C., Ryu, J., Kim, S., Seo, J.W., Shim, H. and Hwang, D.H. (2021) Improvement of depiction of the intracranial arteries on brain CT angiography using deep learning reconstruction IMR Press, pp. 967.
- Petridis, A.K., Kamp, M.A., Cornelius, J.F., Beez, T., Beseoglu, K., Turowski, B. and Steiger, H. (2017) Aneurysmal Subarachnoid Hemorrhage Deutscher Arzte-Verlag GmbH.
- Polkampally, P., Jovin, I. and Bottinor, W. (2013) Adverse Reactions to Iodinated Contrast Media Georg Thieme Verlag KG, pp. 149.
- Power, S.P., Moloney, F., Twomey, M., James, K., O'connor, O.J. and Maher, M.M. (2016) Computed tomography and patient risk: Facts, perceptions and uncertainties Baishideng Publishing Group Inc.
- Raman, S.P., Mahesh, M., Blasko, R.V. and Fishman, E.K. (2013) CT Scan Parameters and Radiation Dose: Practical Advice for Radiologists Elsevier BV, pp. 840.
- Rayz, V.L. and Cohen-Gadol, A.A. (2022) Hemodynamics of Cerebral Aneurysms: Connecting Medical Imaging and Biomechanical Analysis Annual Reviews, pp. 231.
- Rizvi, A., Seyedsaadat, S.M., Alzuabi, M., Murad, M.H., Kadirvel, R., Brinjikji, W. and Kallmes, D.F. (2020) Long-Term Rupture Risk in Patients with Unruptured
- Intracranial Aneurysms Treated with Endovascular Therapy: A Systematic Review and Meta-Analysis American Society of Neuroradiology (ASNR), pp. 1043.
- Saber, M. and Knipe, H. (2015) 'Giant cerebral aneurysm,' Radiopaedia.org [Preprint]. https://doi.org/10.53347/rid-39214.
- Shefer, E., Altman, A., Behling, R., Goshen, R., Gregorian, L., Roterman, Y., Uman, I., Wainer, N., Yagil, Y. and Zarchin, O. (2013) State of the Art of CT Detectors and Sources: A Literature Review Springer Science and Business Media LLC, pp. 76.
- Slettebø, H., Karic, T. and Sorteberg, A. (2020) Impact of smoking on course and outcome of aneurysmal subarachnoid hemorrhage Springer Science and Business Media LLC, pp. 3117.
- Sollmann, N., Mei, K., Riederer, I., Schön, S., Kopp, F.K., Löffler, M.T., Hedderich, D.M., Maegerlein, C., Friedrich, B., Kreiser, K., Boeckh-Behrens, T., Kirschke, J.S., Rummeny, E.J., Zimmer, C., Noël, P.B. and Baum, T. (2019) Tube Current Reduction in CT Angiography: How Low Can We Go in Imaging of Patients With Suspected Acute Stroke? American Roentgen Ray Society, pp. 410.
- Sugrue, G., O'reilly, M.K., Byrne, D., Crockett, M.T., Murphy, S. and Kavanagh, E.C. (2018) CT cervico-cerebral angiography in acute stroke. Can we justify aortic arch imaging? Springer Science

and Business Media LLC, pp. 661.

- Takeyama, N., Kuroki, K., Hayashi, T., Sai, S., Okabe, N., Kinebuchi, Y., Hashimoto, T. and Gokan, T. (2012) Cerebral CT angiography using a small volume of concentrated contrast material with a test injection method: optimal scan delay for quantitative and qualitative performance Oxford University Press (OUP), pp. e748.
- Tamura, Y., Utsunomiya, D., Sakamoto, T., Hirai, T., Nishiharu, T., Urata, J. and Yamashita, Y. (2009) Reduction of Contrast Material Volume in 3D Angiography of the Brain Using MDCT American Roentgen Ray Society, pp. 455.
- Tang, K., Li, R., Lin, J., Zheng, X., Wang, L. and Yin, W. (2015). The Value of Cerebral CT Angiography with Low Tube Voltage in Detection of Intracranial Aneurysms Hindawi Limited, pp. 1.
- Tawk, R.G., Hasan, T.F., D'souza, C.E., Peel, J.B. and Freeman, W.D. (2021) Diagnosis and Treatment of Unruptured Intracranial Aneurysms and Aneurysmal Subarachnoid Hemorrhage Elsevier BV, pp. 1970.
- Tenny S, Thorell W. Intracranial Hemorrhage. [Updated 2023 Feb 13]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK470242/
- Thompson, B.G., Brown, R.D., Amin-Hanjani, S., Broderick, J.P., Cockroft, K.M., Connolly, E.S., Duckwiler, G.R., Harris, C.C., Howard, V.J., Claiborne, S., Johnston, C., Meyers, P.M., Molyneux, A., Ogilvy, C.S., Ringer, A.J. and Torner, J. (2024) Guidelines for the Management of Patients With Unruptured Intracranial Aneurysms A Guideline for Healthcare Professionals From the American Heart Association/American Stroke Association.
- Toth, G. and Cerejo, R. (2018) Intracranial aneurysms: Review of current science and management SAGE Publications, pp. 276.
- Vlak, M.H.M., Rinkel, G.J.E., Greebe, P., Van Der Bom, J.G. and Algra, A. (2011a) Trigger Factors and Their Attributable Risk for Rupture of Intracranial Aneurysms Ovid Technologies (Wolters Kluwer Health), pp. 1878.
- Vlak, M.H.M., Rinkel, G.J.E., Greebe, P., Van Der Bom, J.G. and Algra, A. (2011b) Trigger Factors and Their Attributable Risk for Rupture of Intracranial Aneurysms Ovid Technologies (Wolters Kluwer Health), pp. 1878.
- Wikipedia contributors (2024) Intracranial aneurysm. https://en.wikipedia.org/wiki/Intracranial_aneurysm.
- Xu, Z., Rui, Y., Hagan, J.P. and Kim, D.H. (2020) Intracranial Aneurysms: Pathology, Genetics, and Molecular Mechanisms Springer Science and Business Media LLC, pp. 325.
- Yanagida, T. (2018) Inorganic scintillating materials and scintillation detectors Japan Academy, pp. 75.
- Yang, Z. L., Ni, Q. Q., Schoepf, U. J., De Cecco, C. N., Lin, H., Duguay, T. M., Zhou, C. S., Zhao, Y. E., Lu, G. M., & Zhang, L. J. (2017). Small Intracranial Aneurysms: Diagnostic Accuracy of CT Angiography. Radiology, 285(3), 941–952. https://doi.org/10.1148/radiol.2017162290
- Yoon, N. K., Mcnally, S., Taussky, P. and Park, M. S. (2016). Imaging of cerebral aneurysms: a clinical perspective Springer Science and Business Media LLC.
- Zhou, Y., Wang, J., Dassarath, M., Wang, M., Zhang, Q., Xiong, Y., & Yuan, Q. (2015). Can Radiation Dose Be Reduced and Image Quality Improved With 80-kV and Dual-Phase Scanning of the Lower Extremities With 64-Slice Computed Tomography Angiography?. Journal of computer assisted tomography, 39(5), 657–660. https://doi.org/10.1097/RCT.0000000000000258
- Zuurbier, C. C. M., Molenberg, R., Mensing, L. A., Wermer, M. J. H., Juvela, S., Lindgren, A. E., Jääskeläinen, J. E., Koivisto, T., Yamazaki, T., Uyttenboogaart, M., Van Dijk, J. M. C., Aalbers, M.W., Morita, A., Tominari, S., Arai, H., Nozaki, K., Murayama, Y., Ishibashi, T., Takao, H., Gondar, R., Bijlenga, P., Rinkel, G. J. E., Greving, J. P. and Ruigrok, Y. M. (2022) Sex Difference and Rupture Rate of Intracranial Aneurysms: An Individual Patient Data Meta-Analysis Ovid Technologies (Wolters Kluwer Health), pp. 362.