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COMPARISON OF CONTRAST-ENHANCED AND NON-CONTRAST COMPUTED TOMOGRAPHY IN STROKE DIAGNOSIS: A COMPREHENSIVE REVIEW

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ABSTRACT

Stroke is one of the leading causes of mortality and long-term disability worldwide, requiring rapid diagnosis and timely therapeutic intervention to improve patient outcomes. Computed tomography (CT) remains the first-line imaging modality in the emergency evaluation of suspected stroke because of its widespread availability, rapid acquisition time, and high diagnostic accuracy. Non-contrast computed tomography (NCCT) is the initial imaging technique used to differentiate ischemic stroke from intracerebral hemorrhage, while contrast-enhanced CT techniques, including CT angiography (CTA) and CT perfusion (CTP), provide additional information regarding vascular occlusion, collateral circulation, cerebral perfusion, and tissue viability. Recent advances in multidetector CT technology have significantly improved the early detection of acute ischemic stroke and facilitated evidence-based treatment decisions, particularly regarding thrombolysis and mechanical thrombectomy. This review summarizes current evidence regarding stroke epidemiology, major risk factors, principles of stroke imaging, advantages and limitations of non-contrast and contrast-enhanced CT, diagnostic accuracy, and recent technological developments. Evidence indicates that NCCT remains indispensable for rapid exclusion of hemorrhage, whereas CTA and CTP substantially improve identification of large vessel occlusion, ischemic penumbra, and salvageable brain tissue. Integration of contrast-enhanced imaging into acute stroke protocols has enhanced diagnostic confidence, optimized patient selection for reperfusion therapy, and improved clinical outcomes. Continued advances in artificial intelligence, automated image processing, and multimodal imaging are expected to further strengthen stroke diagnosis and management.

KEYWORDS: Stroke, Computed Tomography, Non-Contrast CT, CT Angiography, CT Perfusion, Ischemic Stroke, Intracerebral Hemorrhage, Diagnostic Imaging.

1. INTRODUCTION

Stroke is a major global public health problem and remains one of the leading causes of mortality, long-term disability, and healthcare expenditure. It occurs when cerebral blood flow is interrupted because of vascular occlusion or rupture, resulting in neuronal injury and irreversible brain damage if treatment is delayed. Stroke is broadly classified into ischemic stroke, accounting for approximately 80–85% of cases, and hemorrhagic stroke, which includes intracerebral hemorrhage and subarachnoid hemorrhage. Early diagnosis is critical because therapeutic interventions such as intravenous thrombolysis and mechanical thrombectomy are highly time dependent.

Computed tomography (CT) has become the cornerstone of emergency stroke imaging because it is rapid, widely available, and capable of differentiating ischemic stroke from intracranial hemorrhage within minutes. Non-contrast computed tomography (NCCT) is recommended as the initial imaging modality for all patients presenting with suspected acute stroke because it rapidly excludes hemorrhage and identifies major early ischemic changes. However, NCCT has limited sensitivity during the earliest hours following ischemic stroke, particularly for small cortical infarctions and posterior circulation strokes.

The development of contrast-enhanced imaging techniques, including CT angiography (CTA) and CT perfusion (CTP), has transformed acute stroke management. CTA enables visualization of intracranial and extracranial blood vessels, facilitating rapid detection of arterial stenosis and large vessel occlusion. CT perfusion provides functional assessment of cerebral blood flow, cerebral blood volume, and mean transit time, thereby distinguishing irreversibly infarcted tissue from potentially salvageable ischemic penumbra. These imaging modalities assist clinicians in selecting appropriate candidates for reperfusion therapies beyond traditional treatment windows.

The present review critically evaluates current evidence comparing contrast-enhanced and non-contrast CT imaging in stroke diagnosis, highlighting their respective advantages, limitations, diagnostic accuracy, and clinical applications in modern stroke management.

2. Global Burden and Epidemiology of Stroke

Stroke continues to impose an enormous burden on healthcare systems worldwide. According to the World Health Organization, stroke remains the second leading cause of death globally and a major contributor to long-term disability. Increasing life expectancy, urbanization, sedentary lifestyles, hypertension, diabetes mellitus, obesity, smoking, and cardiovascular disease have contributed to a steady rise in stroke incidence, particularly in low- and middle-income countries.

Evidence summarized in the thesis indicates that hypertension remains the single most important modifiable risk factor for stroke. A community-based study conducted in Varanasi, India, reported a hypertension prevalence of **32.9%**, with awareness, treatment, and blood pressure control remaining remarkably poor. Approximately **61.6%** of hypertensive individuals were unaware of their condition, highlighting the importance of early screening and preventive healthcare interventions.

Global epidemiological studies further demonstrate substantial regional variation in stroke prevalence and mortality. The burden of stroke has increased considerably in developing countries because of limited access to primary healthcare, delayed diagnosis, inadequate control of vascular risk factors, and restricted access to rehabilitation services. A review cited in the thesis reported that stroke rates in several low- and middle-income countries have approximately doubled during recent decades, whereas incidence has declined in many high-income nations because of improved prevention strategies and healthcare infrastructure.

Population-based studies have consistently identified ischemic stroke as the predominant subtype. Large national surveys have reported that ischemic stroke accounts for approximately 70–80% of all stroke cases, while intracerebral hemorrhage and subarachnoid hemorrhage represent smaller but clinically significant proportions. These epidemiological trends emphasize the importance of rapid neuroimaging to distinguish ischemic from hemorrhagic stroke and guide appropriate therapeutic intervention.

3. Risk Factors for Stroke

Stroke is a multifactorial disease resulting from the interaction of modifiable and non-modifiable risk factors. Understanding these determinants is essential for implementing preventive strategies and reducing the global burden of stroke. Modifiable risk factors, including hypertension, diabetes mellitus, dyslipidemia, smoking, obesity, sedentary lifestyle, excessive alcohol consumption, and cardiovascular diseases, account for the majority of stroke cases. Conversely, non-modifiable factors such as increasing age, male sex, family history, and genetic predisposition influence an individual's susceptibility but cannot be altered.

Hypertension is widely recognized as the most important modifiable risk factor for both ischemic and hemorrhagic stroke. Chronic elevation of blood pressure damages vascular endothelium, accelerates atherosclerosis, and increases the likelihood of cerebral vessel rupture. A community-based study conducted in Varanasi, India, involving 640 adults reported that 32.9% of participants were hypertensive. Alarmingly, 61.6% of hypertensive individuals were unaware of their condition, 72.9% were not receiving treatment, and only a small proportion had adequate blood pressure control. These findings emphasize the urgent need for population-based hypertension screening and effective management programs.

Diabetes mellitus represents another significant contributor to stroke risk. Persistent hyperglycemia promotes endothelial dysfunction, accelerates atherosclerotic plaque formation, and impairs vascular integrity. Epidemiological studies consistently demonstrate that diabetic individuals have approximately twice the risk of developing stroke compared with non-diabetic populations. Furthermore, diabetes is associated with poorer neurological recovery and increased mortality following stroke.

Lifestyle-related factors also play an important role in stroke pathogenesis. Cigarette smoking promotes thrombosis, endothelial injury, oxidative stress, and accelerated atherosclerosis. Obesity and physical inactivity contribute indirectly by increasing the prevalence of hypertension, diabetes, and dyslipidemia. Excessive alcohol consumption has similarly been associated with elevated blood pressure and increased risk of hemorrhagic stroke. Consequently, lifestyle modification remains a cornerstone of primary stroke prevention.

Cardiovascular diseases, particularly atrial fibrillation (AF), substantially increase the risk of ischemic stroke through cardioembolic mechanisms. Patients with AF have a five-fold higher risk of stroke than the general population because thrombi formed within the atria may embolize to cerebral arteries. Studies included in the thesis reported a strong association between atrial fibrillation and cardioembolic stroke, highlighting the importance of early diagnosis and anticoagulant therapy in high-risk patients.

Age remains the strongest non-modifiable determinant of stroke. The incidence of stroke increases exponentially after 55 years because of progressive vascular degeneration, accumulation of cardiovascular risk factors, and age-related physiological changes. Population-based studies have consistently demonstrated that stroke prevalence rises significantly with advancing age in both men and women.

Effective prevention therefore requires comprehensive management of modifiable risk factors through blood pressure control, diabetes management, smoking cessation, healthy dietary habits, regular physical activity, weight reduction, and appropriate treatment of cardiovascular disorders.

4. Non-Contrast Computed Tomography (NCCT) in Stroke Evaluation

Non-contrast computed tomography (NCCT) remains the first-line imaging investigation for patients presenting with suspected acute stroke because of its rapid availability, ease of performance, and ability to reliably identify intracranial hemorrhage. International stroke management guidelines recommend immediate NCCT before initiation of thrombolytic therapy because exclusion of hemorrhage is essential for safe administration of intravenous tissue plasminogen activator (tPA).

NCCT provides excellent visualization of acute intracerebral hemorrhage, subarachnoid hemorrhage, cerebral edema, hydrocephalus, mass lesions, and other intracranial abnormalities that may mimic stroke. Fresh intracranial blood appears hyperdense on CT images, allowing rapid differentiation between ischemic and hemorrhagic stroke. This distinction is clinically critical because thrombolytic therapy is contraindicated in hemorrhagic stroke.

Although highly sensitive for hemorrhage, NCCT demonstrates relatively limited sensitivity for detecting early ischemic changes during the first few hours following symptom onset. Early ischemic findings include loss of gray-white matter differentiation, insular ribbon sign, obscuration of the lentiform nucleus, sulcal effacement, and hyperdense middle cerebral artery (MCA) sign. These subtle abnormalities may be overlooked during the hyperacute phase, particularly by less experienced observers.

One of the major advantages of NCCT is its speed. Modern multidetector CT scanners can acquire complete brain images within a few seconds, minimizing delays in patient management. The widespread availability of CT scanners in emergency departments further supports its role as the initial imaging modality in acute stroke pathways. Additionally, NCCT does not require intravenous contrast administration, eliminating concerns regarding contrast allergy or contrast-induced nephropathy.

Despite these advantages, NCCT has several limitations. Small infarcts, posterior circulation strokes, lacunar infarctions, and very early ischemic lesions may not be visible immediately after symptom onset. Furthermore, NCCT provides limited information regarding vascular occlusion, collateral circulation, and tissue perfusion, all of which have become increasingly important for selecting patients for reperfusion therapies.

Consequently, while NCCT remains indispensable for the rapid exclusion of hemorrhage, additional contrast-enhanced imaging techniques are frequently required to fully characterize ischemic stroke and optimize treatment decisions.

5. Contrast-Enhanced CT in Acute Stroke Imaging

Contrast-enhanced CT techniques—including **CT Angiography (CTA)** and **CT Perfusion (CTP)**—have revolutionized the evaluation of acute ischemic stroke by providing detailed anatomical and functional information beyond that available from NCCT alone. These advanced imaging modalities assist clinicians in identifying arterial occlusion, assessing collateral circulation, evaluating cerebral perfusion, and determining the extent of salvageable brain tissue.

CT Angiography involves intravenous administration of iodinated contrast material followed by rapid image acquisition during arterial enhancement. CTA provides high-resolution visualization of intracranial and extracranial cerebral arteries, allowing accurate identification of arterial stenosis, occlusion, aneurysms, dissections, and vascular malformations. Detection of large vessel occlusion is particularly important because these patients may benefit from mechanical thrombectomy in addition to intravenous thrombolysis.

CT Perfusion complements CTA by evaluating cerebral hemodynamics through quantitative measurement of cerebral blood flow (CBF), cerebral blood volume (CBV), mean transit time (MTT), and time-to-maximum (Tmax). These parameters enable differentiation between the **ischemic core**, representing irreversibly damaged brain tissue, and the **ischemic penumbra**, which remains viable if reperfusion is achieved promptly. Accurate identification of salvageable tissue has substantially expanded the therapeutic window for endovascular intervention in selected patients.

The principal advantage of contrast-enhanced CT lies in its ability to support individualized treatment decisions. Patients demonstrating a small infarct core and substantial penumbra may benefit from reperfusion therapy even beyond the conventional 4.5-hour thrombolysis window, provided imaging criteria are satisfied. This imaging-based approach has significantly improved functional outcomes in acute ischemic stroke.

However, contrast-enhanced CT also has limitations. Administration of iodinated contrast agents may produce allergic reactions and carries a small risk of contrast-induced nephropathy, particularly in patients with impaired renal function. Additional imaging time, increased radiation exposure, and higher costs also represent potential disadvantages compared with NCCT. Nevertheless, in appropriately selected patients, the diagnostic and therapeutic benefits generally outweigh these risks.

Overall, CTA and CTP have become indispensable components of comprehensive stroke imaging protocols, enabling precise diagnosis, optimized patient selection for reperfusion therapy, and improved clinical outcomes.

6. Comparison of Contrast and Non-Contrast CT in Stroke Diagnosis

Computed tomography (CT) has become the cornerstone of emergency stroke imaging because of its rapid image acquisition, widespread availability, and high diagnostic accuracy. Although both non-contrast CT (NCCT) and contrast-enhanced CT techniques play indispensable roles in stroke evaluation, each modality serves a distinct clinical purpose. Their combined use has significantly improved diagnostic precision, therapeutic decision-making, and patient outcomes.

NCCT remains the recommended first-line imaging investigation for all patients with suspected acute stroke. Its principal objective is the rapid exclusion of intracranial hemorrhage before initiation of thrombolytic therapy. NCCT can be completed within minutes and provides excellent visualization of acute hemorrhage, cerebral edema, hydrocephalus, tumors, and other intracranial pathologies that may mimic stroke. However, its sensitivity for detecting hyperacute ischemic changes during the first few hours after symptom onset remains relatively limited, particularly in small cortical infarctions and posterior circulation strokes.

In contrast, CTA and CTP provide detailed vascular and physiological information unavailable through NCCT alone. CTA accurately identifies arterial stenosis, large vessel occlusion, aneurysms, dissections, and collateral circulation, while CTP distinguishes irreversibly infarcted tissue from potentially salvageable ischemic penumbra by measuring cerebral blood flow, cerebral blood volume, and mean transit time. These additional imaging findings are particularly valuable for selecting patients suitable for intravenous thrombolysis or mechanical thrombectomy.

Several comparative studies have demonstrated that multimodal CT imaging significantly improves diagnostic confidence compared with NCCT alone. Patients undergoing CTA and CTP receive more individualized treatment because clinicians can evaluate vessel patency, collateral circulation, infarct core size, and viable brain tissue before deciding upon reperfusion therapy. Consequently, contrast-enhanced imaging has become an integral component of modern acute stroke protocols, particularly in comprehensive stroke centers.

Table 1. Comparison Between Non-Contrast CT and Contrast-Enhanced CT.

Parameter	**Non-Contrast CT (NCCT)**	**Contrast CT (CTA/CTP)**
Contrast administration	Not required	Intravenous iodinated contrast required
Scan duration	2–5 minutes	5–10 minutes
Detection of hemorrhage	Excellent	Excellent
Detection of early ischemia	Moderate	Excellent
Visualization of cerebral arteries	No	Excellent
Detection of vessel occlusion	Limited	Excellent
Evaluation of collateral circulation	No	Excellent
Assessment of ischemic penumbra	No	Excellent
Patient selection for thrombectomy	Limited	Highly effective
Contrast-related complications	None	Possible allergy or nephropathy

The complementary roles of NCCT and contrast-enhanced CT indicate that neither modality should be considered superior in all clinical situations. Rather, each provides unique diagnostic information that contributes to comprehensive stroke evaluation.

7. Diagnostic Accuracy and Clinical Evidence

Recent advances in multidetector CT technology have substantially improved the diagnostic accuracy of stroke imaging. Numerous clinical trials and observational studies have demonstrated that multimodal CT imaging increases sensitivity for acute ischemic stroke while maintaining excellent specificity for intracranial hemorrhage.

NCCT remains nearly 100% sensitive for detecting acute intracerebral hemorrhage, making it indispensable during emergency evaluation. However, early ischemic changes may not become radiologically apparent until several hours after symptom onset. Studies have reported NCCT sensitivity ranging from approximately 45% to 70% during the hyperacute phase of ischemic stroke.

Conversely, CTA demonstrates excellent sensitivity and specificity for detecting large vessel occlusion, frequently exceeding 95%. Accurate identification of proximal arterial occlusion enables rapid selection of patients suitable for mechanical thrombectomy, thereby significantly improving neurological recovery.

Similarly, CT perfusion has demonstrated remarkable value in identifying ischemic penumbra. Several landmark randomized clinical trials have shown that imaging-guided reperfusion therapy based on CTP findings improves functional outcomes, even among patients presenting beyond traditional therapeutic time windows.

The thesis findings support these observations, indicating that contrast-enhanced CT substantially improved diagnostic confidence and facilitated more accurate differentiation between ischemic and hemorrhagic stroke compared with NCCT alone. These findings further emphasize the importance of integrating advanced imaging into contemporary stroke management protocols.

8. Recent Advances in Stroke Imaging

Technological innovations have transformed stroke imaging over the past decade. Artificial intelligence (AI), deep learning algorithms, automated perfusion software, and cloud-based image processing platforms now provide rapid interpretation of CT images, reducing reporting time and improving diagnostic accuracy.

AI-assisted software can automatically identify intracranial hemorrhage, quantify ischemic core volume, detect large vessel occlusion, and calculate Alberta Stroke Program Early CT Score (ASPECTS). Automated alerts immediately notify stroke specialists, reducing treatment delays and improving patient outcomes.

Dual-energy CT and spectral CT technologies have further enhanced tissue characterization by improving differentiation between hemorrhage, contrast staining, calcification, and ischemic tissue. These innovations reduce diagnostic uncertainty and support more precise clinical decision-making.

Tele-radiology has also expanded access to specialist interpretation, particularly in rural and underserved regions. Real-time transmission of CT images allows neuroradiologists to provide rapid consultation, facilitating timely initiation of thrombolysis or referral for thrombectomy.

Future developments integrating AI with multimodal CT imaging are expected to further improve diagnostic accuracy, workflow efficiency, and personalized treatment strategies for acute stroke patients.

9. Future Perspectives

Future stroke imaging will increasingly emphasize precision medicine through integration of artificial intelligence, machine learning, advanced image reconstruction algorithms, and multimodal imaging platforms. Automated decision-support systems capable of rapidly identifying stroke subtype, estimating infarct progression, and predicting treatment response are expected to enhance emergency stroke care.

Research should continue to evaluate novel CT biomarkers capable of predicting neurological recovery and long-term functional outcomes. Development of lower-dose CT protocols, improved contrast agents, portable CT scanners, and hybrid imaging systems will further increase accessibility while reducing radiation exposure and contrast-related complications.

Expansion of stroke centers, standardized imaging protocols, and continuous professional training for radiologists and emergency physicians will remain essential for maximizing the benefits of advanced CT technologies.

10. CONCLUSION

Stroke remains a major cause of mortality and disability worldwide, making rapid neuroimaging fundamental to effective patient management. Non-contrast computed tomography continues to serve as the cornerstone of emergency stroke evaluation because of its rapid availability, ability to exclude intracranial hemorrhage, and widespread accessibility. However, NCCT alone provides limited information regarding vascular occlusion and cerebral perfusion.

Contrast-enhanced CT techniques, including CT angiography and CT perfusion, have significantly improved stroke diagnosis by accurately identifying large vessel occlusion, collateral circulation, ischemic core, and salvageable brain tissue. These imaging modalities have expanded eligibility for reperfusion therapy and substantially improved functional outcomes in patients with acute ischemic stroke.

Evidence reviewed in this article demonstrates that NCCT and contrast-enhanced CT should be regarded as complementary rather than competing imaging techniques. NCCT remains indispensable for the immediate exclusion of hemorrhage, whereas CTA and CTP provide comprehensive vascular and perfusion assessment necessary for individualized therapeutic decision-making. Integration of multimodal CT imaging into standardized stroke protocols has become the current standard of care in comprehensive stroke centers.

Future advancements in artificial intelligence, automated image analysis, and precision imaging are expected to further improve diagnostic accuracy, reduce treatment delays, and enhance patient outcomes. Continued research, technological innovation, and implementation of evidence-based imaging protocols will remain essential for optimizing stroke diagnosis and management.

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