ORIGINAL RESEARCH

The Diagnostic Advantages of MRI in Cerebral Infarction: Multi-Sequence Imaging and Improved Sensitivity in Early Detection

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ABSTRACT

Objective • The study aimed to investigate the diagnostic value of computed tomography (CT) and magnetic resonance imaging (MRI) in cerebral infarction (CI) in cerebrovascular diseases.

Method • 100 patients with acute ischemic cerebral infarction (AICI) were divided into a CT group and an MRI group. The diagnostic efficacy of the two diagnostic methods for CI was compared and analyzed.

Results • Only 6 patients with acute early stage (AES) CI and 30 patients with acute late stage (ALS) CI were detected by CT, which was significantly less than those detected by MRI ($P < .05$); 5 patients with <5 mm infarction were detected by CT in ALS and 10 patients with 5-15 mm infarction were detected by CT in ALS, which were significantly less than those detected by MRI ($P < .05$); 3 patients were diagnosed with cerebral sulcus, fissure, and shallow and disappeared brain cistern, 4 patients with local gyrus swelling, and 31 patients with significant swelling by CT examination, which was significantly less than those detected by MRI ($P < .05$); the infarct area ratio measured by CT/ diffusion weighted imaging (DWI) was significantly lower than that measured by fluid attenuated inversion recovery (FLAIR)/DWI ($P < .05$); the diagnostic specificity (Sp), sensitivity (Se), Youden index, positive predictive value (PV), and negative PV of MRI were 0.82, 0.79, 0.58, 0.7, and 0.88, respectively, which were significantly better than those of CT ($P < .05$).

Conclusion • CT is not a sensitive technique for the diagnosis of early CI. Compared to CT, MRI has the characteristics of multi-sequence and multi-parameter imaging, is more sensitive to infarction within 2 hours after onset, and can more clearly and accurately diagnose CI. (*Altern Ther Health Med.* [E-pub ahead of print.])

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INTRODUCTION

Due to the aging population, the prevalence of cerebrovascular disease is gradually increasing.[1] Cerebrovascular-related lesions encompass a wide range of types, and the causes of the disease are complex and diverse. They are typically classified into two categories: acute[2] and chronic[3] lesions. Acute cerebrovascular disease refers to a sudden disruption of blood circulation in the brain, often resulting in focal neurological impairment. On the other hand, cerebrovascular chronic lesions initially exhibit no obvious clinical symptoms and gradually progress over time.

Acute ischemic cerebral infarction (AICI) is a condition where blood circulation disorders in the cerebral artery, vertebrobasilar artery trunk, and its branches cause ischemia, hypoxia, and eventual necrosis of the corresponding brain tissue within three days of onset.[4] The prevalence of AICI has been increasing over the years, accounting for approximately three-quarters of all acute cerebrovascular diseases. It is associated with poor prognosis, high recurrence rates, significant disability, and a mortality rate of 10%-15%. In the elderly population, the disease is mainly caused by atherosclerosis, hypertension, and diabetes, and unfortunately changes in lifestyle and dietary patterns have led to a decrease in the age of onset.[5] Clinical manifestations and imaging findings differ between young adults and the elderly, often resulting in misdiagnosis of cerebral infarction (CI) as a mental disorder due to mild or asymptomatic symptoms. Delayed treatment due to misdiagnosis can lead to the progression of infarcts, mass effect, and even cerebral herniation.[6]

Early diagnosis and timely treatment can inhibit the continuous development of small infarcts caused by collateral circulation disorders into large infarcts, promote the normalization of blood supply of the main trunk of cerebral arteries and other branches around the infarction, prevent the brain tissue from being in the ischemic and hypoxic state for a

long time, reduce the compression of other normal brain tissues by brain edema tissues, and promote the normal operation of its nerve conduction pathway.[11,12] Furthermore, it can also protect some important cranial nerve tissues, such as the thermoregulatory center, avoid damaging other organs, reduce the possibility of recurrence, and reduce the disability rate of patients. The optimal treatment window for CI is within six hours of onset. If timely treatment is not received, restoring the injured brain cells becomes extremely challenging even if the subsequent blood supply is restored, and there will be risks of secondary cerebral hemorrhage, reperfusion injury, etc.[13]

Computed tomography (CT) and magnetic resonance imaging (MRI) are the key diagnostic tools used for CI. However, diagnosing early CI poses several challenges and limitations with existing diagnostic methods.

CT is a highly efficient imaging modality that completes axial scanning of the brain within approximately 10 seconds. It is particularly effective in the acute phase of cerebral hemorrhage, as it allows for macroscopic recognition of the condition. However, in the hyperacute stage (HAS) or acute early stage (AES) of CI, CT with its limited sensitivity may not be able to accurately detect the infarct site due to the minimal difference in CT values between the lesion and surrounding normal brain tissue. Additionally, smaller infarcts may not be visible within 24 hours of onset, potentially delaying optimal treatment timing.[7] Another limitation of CT is the inability to accurately characterize CI lesions. CT imaging, although efficient and widely accessible, cannot differentiate between different types of brain tissue and may not provide sufficient contrast to identify early ischemic changes. Additionally, the visualization of certain anatomical features, such as cerebral sulci, fissures, and brain cisterns, may be suboptimal with CT.

Magnetic resonance imaging (MRI), on the other hand, specifically T1-weighted imaging (T1WI) and T2-weighted imaging (T2WI) sequences, offers advantages in imaging CI. These sequences avoid bone artifacts and allow for better visualization of the infarcted area. Fluid-attenuated inversion recovery (FLAIR) sequences are particularly useful in suppressing normal cerebrospinal fluid signals.[8] Diffusion-weighted imaging (DWI) is a unique MRI sequence that detects the diffusion motion of water molecules, providing valuable information about living tissues without causing harm to the subject.[9] Ischemic CI lesions can disrupt the blood-brain barrier, leading to subtle changes even before the barrier is fully damaged. DWI sequences are highly sensitive to these changes, enabling early diagnosis. Within two hours of onset, CI can cause cytotoxic brain edema, characterized by unusual swelling of brain cells, and DWI sequences in MRI can demonstrate high signal intensity in the affected areas, thus facilitating the diagnosis of CI. For patients with AICI, early diagnosis, accurate determination of infarct size and its location, and evaluation of the severity of the disease can help to initiate the corresponding treatment measures within 6 hours after onset can effectively improve the prognosis of patients.[10]

The study seeks to compare the diagnostic efficacy of CT and magnetic resonance imaging (MRI) specifically in the early detection of CI. By focusing on the early stages of CI, the study aims to determine whether MRI, with its multi-sequence and multi-parameter imaging capabilities, can provide superior sensitivity and accuracy compared to CT.

The research aims to fill the gap in knowledge regarding the diagnostic value of these two imaging modalities in early CI detection by providing comparative data on their detection rates and imaging findings, thereby guiding clinicians in selecting the most appropriate and effective diagnostic tool for timely intervention. The significance of this research objective and subsequent findings lies in the importance of early and accurate diagnosis of CI to provide timely treatment and improve patient outcomes.

STUDY METHODS

Ethics and Consent

The protocol was approved by the ethics committee of First People's Hospital of Linping District, No.59872913. Informed consent was obtained from all study participants. All the methods were carried out in accordance with the Declaration of Helsinki.

Study Subjects

A total of 100 patients (62 males and 38 females, aged 46-77 years, mean age 61.3 ± 5.7 years) with AICI who visited the emergency department of First People's Hospital of Linping District from January 2021 to January 2022 were selected as the study subjects. They were divided into CT group and MRI group according to the detection method. According to the onset time, 34 cases were designated as HAS: onset time less than 6h; 33 cases as AES: onset time between 6h-24h; and, 33 cases as acute late stage (ALS): onset time between 1 and 3 days.

Inclusion and Exclusion Criteria

Inclusion criteria: All included cases were first-time patients; the duration of illness did not exceed 3 days; patients diagnosed as acute CI by clinical diagnosis; all patients can tolerate CT and MRI examination, no contraindications of MRI examination; all patients and their families were aware of and voluntarily participated in the trial and signed informed consent.

Exclusion criteria: Patients diagnosed with acute cerebral hemorrhage by CT and hypertensive encephalopathy by MRI; patients with a previous history of brain infection, trauma, or transient ischemic attack; patients with mental illness, unable to communicate normally.

Test Method

CT Examination. A Siemens 64 CT Definition AS scanner was used for the study. The scanning parameters included a slice thickness of 5 mm, slice distance of 6 mm, tube voltage of 140 kV, tube current of 300 mA, and a matrix size of 512 × 512. Axial scanning was performed using the

orbitomeatal baseline, which involved drawing a straight line along the outer canthus and the upper edge of the external auditory foramen, and the scan was performed parallel to this line. The conventional brain window with a window level of 40 HU and a window width of 100 HU was selected for observation. In cases where slightly low-density lesions were present, a CT thin-section scan and a narrow window with a high window level of 55 HU and a narrow window width of 70 HU were used for observation.

The CT diagnostic criteria included the following observations: low-density lesions in the brain parenchyma, disappearance of the gray-white matter interface, shallow or absent sulcal fissures, swelling of the gyri, and the presence of an evident arterial dense sign in the middle cerebral artery. The criteria for a dense sign in a single artery were based on a significant increase in density, with the CT value exceeding 60 HU and a minimum difference of more than 15 HU compared to the density value of the contralateral artery. Generally, the density observed in CT images was classified into four equal grades: slightly low-density lesions, low-density lesions, iso-dense lesions, and significantly low-density lesions. The corresponding CT value ranges were approximately 25-29 HU, 30-34 HU, 35-40 HU, and 20-24 HU, respectively. In the acute phase, the CT value of CI lesions was lower than 25 HU, and the relative CT value (rCT) of symmetrical parts on the affected/unaffected side was lower than 80%.

MRI Test. GE 1.5T Signa HDxt MRI scanner was employed, and the scanning parameters are shown in Table 1.

The baseline for axial MRI scans was determined by combining the coronal view, which showed the septum pellucidum, with the midsagittal view. Specifically, the baseline was defined as a line perpendicular to the falx cerebri in the coronal view and parallel to the anteroposterior horn of the lateral ventricles in the midsagittal view. The conventional sequences used in MRI included T1WI, T2WI, and FLAIR. T1WI sequences employed spin echo (SE) techniques, while T2WI sequences used fast spin echo (FSE). Special sequences, such as DWI, utilized spin echo-echo planar imaging (SE-EPI). Both CT and MRI axial scans covered the range from the medulla oblongata to the parietal cortex.

For MRI diagnostic criteria, the following observations were considered: low signal intensity on T1WI sequences, high signal intensity on T2WI and FLAIR sequences, high signal intensity on DWI sequences, and a corresponding decrease in the apparent diffusion coefficient (ADC). Additionally, certain features were noted, such as shallow or absent sulcal fission, blurred demarcation between gray and white matter, and the presence of mass effect in the cortex. In the acute phase, the ADC value of CI lesions was found to be lower than 0.59×103 mm^2/s , the relative ADC (rADC) value of symmetrical sites on the affected/unaffected side was lower than 60%, and a complete set of DWI sequence images were obtained.

The final diagnosis was determined by three experienced radiologists who independently reviewed the obtained CT and MRI images using a single-blind method. In cases of differing opinions, the radiologists discussed the findings until a consensus was reached. The relationship between CT density and MRI signal is provided in Table 2.

Table 1. MRI Scan Parameters

Parameters	T1WI	T2WI	FLAIR	DWI
TR (ms)	320	3700	7619	7619
IR (ms)	---	---	8000	---
TE (ms)	15	100	100	110
Flip angle	90°	90°	90°	90°
Frequency coding	256	256	256	100
Phase coding	192	224	192	64
NEX	4	2	2	2
Slice thickness (mm)	5	5	5	5
Slice distance (mm)	6	6	6	6
Number of layers	16	16	16	16
FOV	220	220	220	220
Window Level	500	500	500	500
Window width	1000	1000	1000	1000

Table 2. Relationship Between CT Density and MRI Signal

	CT	T1WI	T2WI	FLAIR	DWI
HAS	Iso-dense focus	High signal	Iso-intensity	Iso-intensity	Iso-intensity
AES	Slightly low-density focus	High signal	Slightly high signal	Slightly high signal	Slightly low signal
ALS	Low-density focus	High signal	High signal	High signal	Low signal

Image Processing Methods

The obtained image maps were processed using the PACS workstation corresponding to CT or MRI, respectively. If the CT image showed low-density lesions and significantly low-density lesions, the number of AICI cases was further determined by MRI scan; If the patient exhibited clinical manifestations of CI, but the CT conventional brain window showed iso-dense or slightly low-density findings, we observed the sensitivity of CT in detecting AICI lesions using a combination of 2 mm thin-sections and a narrow window (high window level 55HU, narrow window width 70HU). MRI plain scan, especially DWI sequence, was performed to determine the number of AICI cases increased, and the detection improvement rate was calculated according to the calculation equation: detection improvement rate = .

The area of region of interest (ROI) of AICI lesions was measured, which was regularly round or round infarcts, more irregularly oval infarcts, and irregularly patchy, wedge-shaped, and triangular infarcts. The measurement was performed using both the direct multiplication method and the delineation measurement method. Three measurements were taken at the central layer, and the average value was calculated to minimize errors resulting from manual operation or partial volume effects.. In the direct multiplication method, CT images were based on the central level of low or obvious low-density lesions, and their length and maximum diameter were measured. MRI measurements were based on the central level of high or obvious high signal intensity of DWI sequence images, and their length and maximum diameter were measured on FLAIR and DWI sequence images. Then, the area was calculated by direct multiplication. In the delineation measurement method, the edge of the infarction lesion was delineated on CT image, FLAIR, and DWI sequence images was used to assess the

average area, and finally CT/DWI and FLAIR/DWI ratio were used.

Diagnostic Value Assessment Methods

Sensitivity (Se), Specificity (Sp), Youden index, positive predictive value (PV), and negative PV (with discharge diagnosis as the "gold standard") of CT or MRI in the diagnosis of cerebrovascular disease were studied using a fourfold table.[14]

(1) Se: The percentage of patients with a positive "gold standard" diagnosis who also have a positive MRI or CT diagnosis. High Se causes a low missed diagnosis rate. Se=a/(a+c)×100% Where *a* represents the number of patients diagnosed as CI positive; *c* represents the number of patients diagnosed as CI negative.

(2) Sp: The percentage of patients with a negative "gold standard" diagnosis who also have a negative MRI or CT diagnosis. High Sp causes a low missed diagnosis rate. Pe=d/(b+d)×100% Where *b* represents the number of patients diagnosed as CI positive in non-patients; *d* represents the number of patients diagnosed as CI negative in non-patients.

(3) Youden index: Global assessment of the diagnostic accuracy of patients using MRI or CT. Youden index=Se+Sp-l

(4) Positive PV (PV+): It refers to the proportion of patients diagnosed as CI positive by CT or MRI in confirmed patients. PV+=a/(a+b)×100%

(5) Negative PV (PV-): It refers to the proportion of patients diagnosed as CI negative by CT or MRI in undiagnosed patients. PV-=d/(c+d)×100%

Statistical Methods

SPSS 22.0 statistical processing software was used to process the data. The measurement data were expressed as mean ± standard deviation. Independent sample *t* test was used to compare the mean values of the two groups. One-way analysis of variance was used to compare the mean values of multiple groups. The *q* test was applied to compare the mean values of each pairwise combination within the multiple groups. $P < .05$ was considered statistically significant.

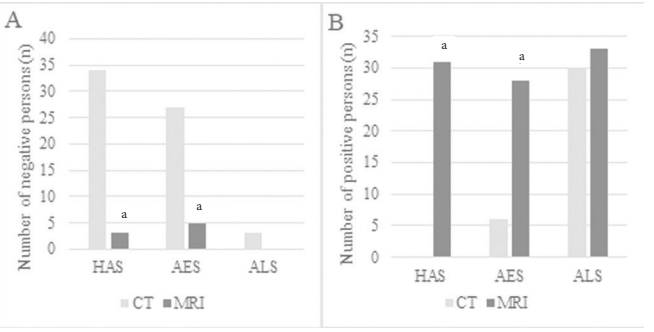
RESULTS

Comparison of Detection of CI Between CT and MRI

The detection results showed that CI patients in HAS were not detected by CT, whereas, 31 cases were detected by MRI, and the difference between the two groups had statistical significance ($P < .05$). 6 cases of CI in AES were detected by CT, while 28 cases of CI in AES were detected by MRI, and the difference between the two groups had statistical significance ($P < .05$). 30 cases of CI in ALS were detected by CT, 33 cases of CI in ALS were detected by MRI, and the difference between the two groups had no statistical significance ($P > .05$) (Figure 1).

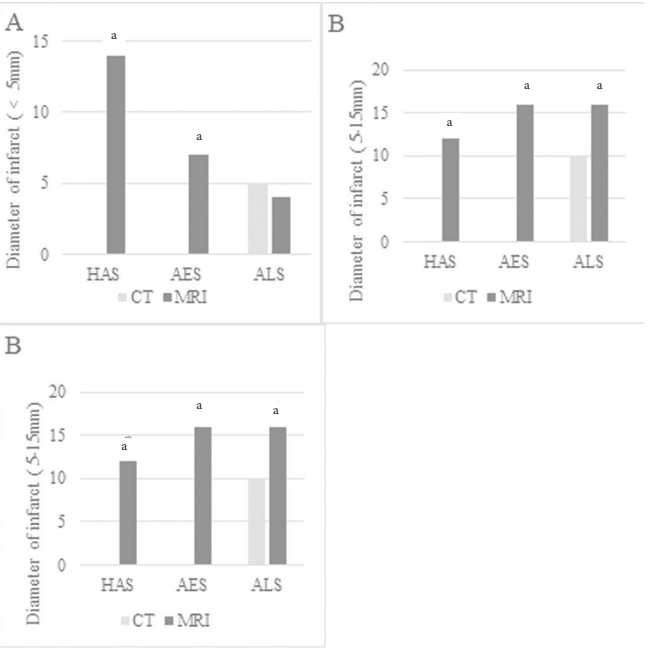
According to statistics, CT only detected 5 cases of infarction lesions (<5 mm) in ALS, while MRI could detect infarction lesions (<5 mm) in 25 cases at each stage of disease progression, and the difference between the two groups was statistically significant ($P > .05$), as shown in Figure 2A. For infarction lesions of 5-15 mm, CT only detected 10 cases in ALS, while MRI could detect infarction lesions in 44 cases at each stage, and the difference between the two groups was statistically significant ($P > .05$), as shown in Figure 2B. For infarction lesions more than 15 mm, CT could detect infarction lesions in both AES and ALS, and the difference between CT and MRI diagnostic results was not statistically significant ($P > .05$), as shown in Figure 2C. Overall, the number of infarcts detected increased as the disease progressed, and MRI could detect significantly more infarcts than CT.

Figure 1. Comparison of CI Detection



[a]Indicates Statistically Significant Difference Compared with CT Detection Results, $P < .05$

Figure 2. Detection Comparison of CI Size Distribution

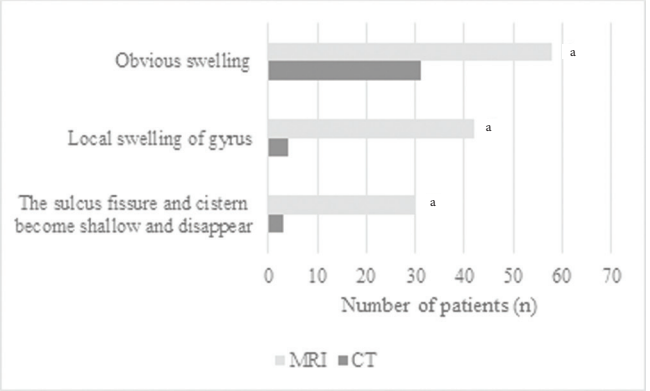


[a]Indicates that Compared with CT Detection Results, the Difference was Statistically Significant, $P < .05$

CT and MRI Signs Comparison of CI

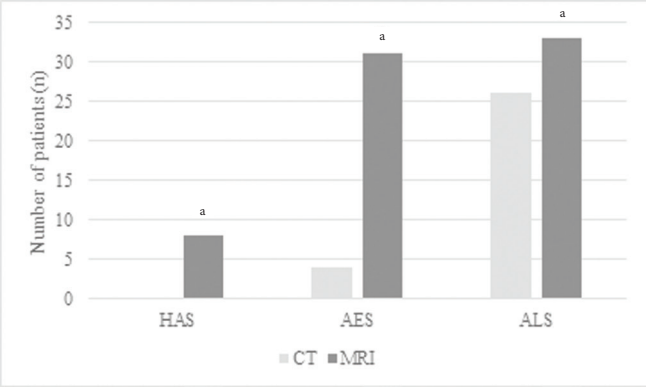
CT examination detected sulcal fissure and cisternal shallowing and disappearance in 3 cases, local gyrus swelling in 4 cases, and significant swelling in 31 cases. Whereas MRI detected sulcal fissure and cisternal shallowing and disappearance in 30 cases, local gyrus swelling in 42 cases,

Figure 3. Detection Comparison of Different Signs



[a]Indicates that there was a Significant Difference Compared with CT Detection Results, $P < .05$

Figure 4. Detection Comparison of CI Arterial Sign



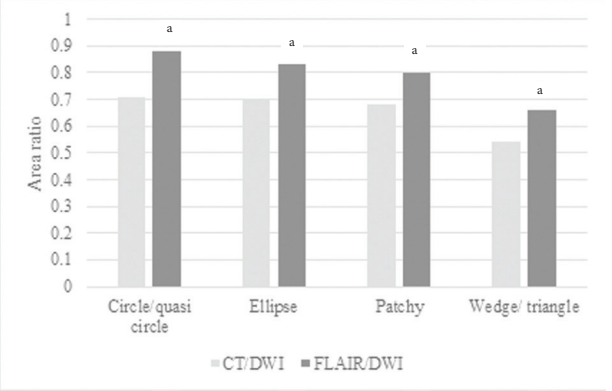
[a]Indicates that there was a Significant Difference Compared with CT Detection Results, $P < .05$

and significant swelling in 58 cases, and the difference between the two groups was statistically significant ($P < .05$) (Figure 3). With the progression of the disease, CT arterial dense sign gradually increased; although it did not detect HAS cases, it was found in 4 AES cases and 26 ALS cases. On the other hand, the FLAIR sequence line-like high signal intensity in MRI was found in 8 HAS cases, 31 AES cases, and 33 ALS cases; and the difference between the two groups was statistically significant ($P < .05$) (Figure 4).

Comparison of CI Lesion Area Delineation Between CT and MRI

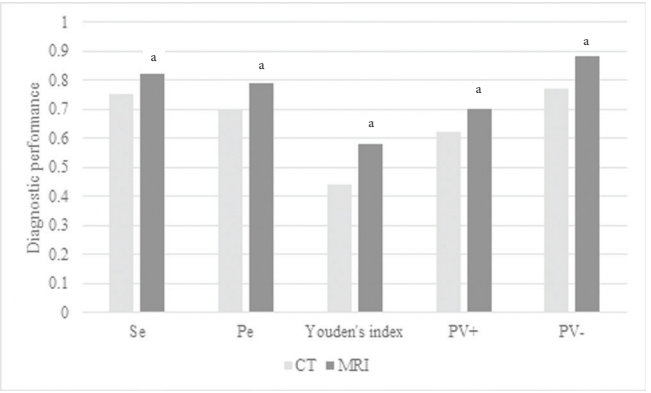
For the regular round/round infarct, the CT/DWI area ratio was 0.71 and the FLAIR/DWI area ratio was 0.88; for more regular oval shape infarct, the CT/DWI area ratio was 0.7 and the FLAIR/DWI area ratio was 0.83; for less regular patchy shape infarct, the CT/DWI area ratio was 0.68 and the FLAIR/DWI area ratio was 0.8; for this significantly irregular wedge and triangle shape infarct, the CT/DWI area ratio was 0.54 and the FLAIR/DWI area ratio was 0.66. There were significant differences between the two methods in the area measurement of each shape of infarction ($P < .05$) (Figure 5).

Figure 5. Comparison of Infarct Size Delineation



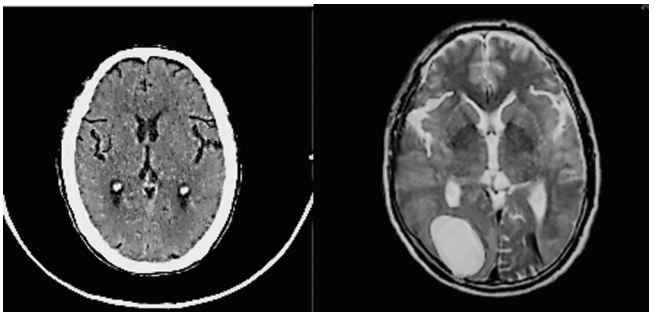
[a]Indicates Statistically Significant Difference Compared with CT/DWI Measurements, $P < .05$

Figure 6. Comparison of Diagnostic Efficacy Between the Two Methods



[a]Indicates that there was a Significant Difference Compared with CT Test Results, $P < .05$

Figure 7. Examples of CT and MRI Detection Images



Comparison of CT and MRI Diagnostic Efficacy

The results showed that the Sp, Se, Youden index, positive PV, and negative PV of CT in the diagnosis of CI were 0.75, 0.7, 0.44, 0.62, and 0.77, respectively, and the Sp, Se, Youden index, positive PV, and negative PV of MRI in the diagnosis of CI were 0.82, 0.79, 0.58, 0.7, and 0.88, respectively. The diagnostic efficacy of MRI was significantly better than that of CT ($P < .05$) (Figure 6). CT showed multiple small lacunar infarction lesions without definite hemorrhage or CI lesions (Figure 7A), while MRI was more accurate and sensitive in the central nervous system (Figure 7B).

DISCUSSION

Early diagnosis of acute ischemic cerebral infarction (AICI) plays a critical role in patient treatment, as timely intervention can effectively reduce the extent of brain injury, minimize complications, and improve patient prognosis.[15] When it comes to imaging techniques, CT scans are typically performed using axial scanning along the orbitomeatal baseline, which is a line drawn through the outer canthus and the upper edge of the external auditory foramen. In contrast, axial MRI scans are determined using coronal and midsagittal views through the septum pellucidum, with lines perpendicular to the falx cerebri in the coronal view and parallel to the anteroposterior horn of the lateral ventricles in the sagittal view. It should be noted that if a patient's position during the CT scan deviates, such as having an extended back or raised head, or if there is brain deviation due to postural influences, the scan line may not be parallel to the orbitomeatal baseline even with the maximum tilt angle of the gantry. As a result, image artifacts may occur. On the other hand, axial MRI scanning is not affected by brain retroversion or left-right deviation, allowing for comprehensive brain visualization and accurate axial images at all levels.[16]

Upon comparison of the measurement of infarct size, it was found that the FLAIR/DWI ratio provided more accurate results than the CT/DWI area ratio. In the early stages of acute CI, vasogenic brain edema occurs due to blood-brain barrier damage and the efflux of intracellular water, while the extracellular space remains narrow. In the case of acute large stroke (ALS), the extracellular water further increases.[17] MRI sequences, specifically DWI, can detect cytotoxic brain edema within two hours of CI onset, whereas CT has lower sensitivity for detecting cytotoxic brain edema, typically detecting it around one day after cerebral ischemia and hypoxia when blood-brain barrier disruption leads to vasogenic brain edema and liquefaction necrosis becomes apparent.[18] In terms of the number of infarcts detected, MRI outperformed CT in patients with CI in both hemispheric and arterial territories (HAS and AES), with MRI detecting significantly more infarcts than CT ($P < .05$). Moreover, the number of infarcts detected increased with disease progression, and MRI consistently detected more infarcts than CT. Other studies have also shown that CT fails to detect infarcts within 2-3 hours of disease onset, whereas MRI demonstrates good diagnostic efficacy in the early stages of CI,[19,20] which is consistent with the findings of this study.

It was found that MRI was significantly better than CT in the diagnosis of sulcal fissure and cistern shallowing, disappearance, local gyrus swelling, and significant swelling; with the progression of the disease, CT arterial dense sign and FLAIR sequence line-like high signal intensity in MRI increased significantly and MRI diagnosed more accurately than CT. The basic density of infarction foci in early CT images was like that of surrounding normal brain tissues. For large areas, CT scans faintly showed blurred boundary, unclear gray and white matter demarcation, slight mass effect, slight swelling of the sulcal fissure, and mild ventricular compression, however, they were still insensitive to small and medium-sized infarction foci; while T1WI sequences were equal or slightly hypointense, T2WI and FLAIR sequences were slightly hyperintense, and DWI sequence signals continued to increase. Therefore, compared to the CT technique, MRI registered a higher rate of detection. The skull is composed of three layers: outer plate, diploe, and inner plate. The inner and outer plates are dense bones and generally do not contain water, so significant high-density lesions are usually observed during CT scanning of the skull, and equal or slightly low-density lesions of acute cortical infarcts are not easily found. However, when the MRI technique was used, MRI sequences showed no signal intensity in the inner and outer plates; while diploe was a loose venular plexus, which was connected to the intracranial and extracranial veins through the guide hole, showed slightly low signal intensity. Acute cortical infarction shows high signal intensity, so significant differences between the affected and surrounding tissues could be observed macroscopically, and MRI was superior to CT examination in the resolution of brain soft tissue.[21] Finally, the diagnostic efficacy of MRI and CT in CI was compared, and the results showed that the Sp, Se, Youden index, positive PV, and negative PV of MRI in the diagnosis of CI were significantly better than those of CT.

In terms of limitations, it is important to note that this study has a relatively small sample size, as it includes only 100 patients with AICI. This sample size may limit the generalizability of the findings to larger populations. Additionally, the study was conducted at a single hospital in a specific geographic location, which could introduce potential selection bias and limit the external validity of the results. It would be beneficial to replicate this study with larger and more diverse samples from multiple healthcare settings to enhance the generalizability of the findings.

Furthermore, the study focused on comparing the diagnostic efficacy of CT and MRI in detecting CI, but it did not directly evaluate the impact of these imaging modalities on patient outcomes or treatment decisions. Future studies could explore the clinical implications and long-term prognostic value of early detection using CT and MRI in patients with CI.

CONCLUSION

In conclusion, the key findings of the study can be summarized as follows: MRI showed higher sensitivity and specificity compared to CT in detecting CI, particularly in the early stages. MRI's multi-sequence and multi-parameter imaging capabilities, such as T1 weighted imaging, T2 weighted imaging, FLAIR sequences, and DWI, contributed to better visualization and accurate diagnosis of CI lesions. These findings support the notion that MRI has distinct advantages over CT in the diagnosis of CI.

Future research can build upon this study by conducting larger-scale studies with diverse populations and examining the impact of early CI diagnosis using CT and MRI on patient outcomes. This will further help to establish the

diagnostic value of these imaging modalities and provide stronger evidence for their clinical application in the management of CI.

AUTHOR DISCLOSURE STATEMENT

The authors declare that they have no competing interests.

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