RESEARCH ARTICLE

Diagnostic utility of CT Hounsfield unit for accurate classification of ischemic and haemorrhagic stroke

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Abstract:

This study examines the diagnostic value of Hounsfield Unit (HU) measurements on computed tomography (CT) in differentiating ischemic from haemorrhagic stroke, a distinction critical for timely and appropriate clinical intervention. The study aims to quantify HU values for both stroke types and assess their correlation with stroke lesion size and volume. Non-contrast enhanced CT brain images were retrospectively reviewed from the PACS. HU values, demographic characteristics, clinical risk factors, and stroke classifications were analysed quantitatively. The results demonstrated a lower mean HU value in ischemic strokes (24.37 ± 5.85) as compared with haemorrhagic strokes (57.17 ± 20.10). Lesion volume was significantly correlated with haemorrhagic stroke ($r = 0.829$, $p = 0.041$). These findings highlight the utility of HU values as a potential imaging marker for distinguishing ischemic from haemorrhagic stroke. This may improve diagnostic accuracy and support more information in clinical decision-making, hence contributing to better stroke assessment and management.

Keywords: Computed tomography, haemorrhagic stroke, Hounsfield unit (HU), ischemic stroke

1. INTRODUCTION

Stroke is the second leading cause of death globally after heart disease (Gautam & Raman, 2021), with approximately 15 million individuals affected each year (Camporesi et al., 2023). In Malaysia, stroke remains a major public health concern and is the third leading cause of mortality (Hwong et al., 2021). Stroke ranks as the third most common cause of death among men and the second among women, following ischemic heart disease (Ching et al., 2019). The World Health Organization (WHO) reports six new stroke cases every hour in Malaysia, with ischemic strokes accounting for 79.4% and haemorrhagic strokes 18.2% of cases (Danial et al., 2023).

Despite advancements in stroke management, survivors still face high mortality and recurrence rates, and outcomes of long-term research on long-term outcomes remains limited (Hwong et al., 2021). Early diagnosis within the first hour of onset especially is critical for minimizing irreversible neurological damage (Akbarzadeh et al., 2021). CT imaging is widely recommended as the first-line modality for acute stroke evaluation due to its speed, accessibility, and ability to differentiate stroke types (Vincent et al., 2023). HU values that derived from CT imaging may offer additional diagnostic value by providing quantitative information on tissue density, which may improve diagnostic accuracy and support treatment decisions. Quantitative measurement of tissue density on non-contrast CT through HU values can enhance the objectivity and diagnostic yield of acute stroke imaging. HU values reflect the linear attenuation of intracranial tissues and enable differentiation between normal brain parenchyma (e.g., grey and white matter) and pathological states such as ischaemia or haemorrhage (Coskun et al., 2025). Utilization of HU-based assessment thus provides a quantitative, reproducible adjunct to visual interpretation, potentially improving early stroke classification and guiding timely treatment decisions. However, diagnostic utility of HU values in distinguishing ischemic from haemorrhagic stroke in Malaysian population is not well reported. This study aims to evaluate HU values across stroke types and correlation between HU values, lesion size and volume.

2. MATERIALS AND METHODS

2.1 Ethical approval

Ethical approval was granted from the UiTM Research Ethics Committee (FERC/FSK/MR/2024/00080) and Hospital Al-Sultan Abdullah (HASA) UiTM research ethics (500-HUiTM (PJI.18/4/89). As a retrospective study in nature, informed consent was not required.

2.2 Study design

This retrospective single-centre study reviewed stroke patients' data acquired from non-contrast CT scans between December 2022 and December 2023. Non-contrast brain CT scans were acquired with lateral 256 mm topogram, 120 kV and 390 mAs reference, 1.0 mm slice thickness and 0.7 mm reconstruction increment using medium smooth kernel (Siemens SOMATOM Definition AS+128 MDCT, Siemens Healthineers, Germany). Medical records were reviewed using the Picture Archiving and Communication System (PACS) and the Electronic Hospital Record (EHR).

2.3 Sampling and population

A purposive sampling technique was used to select patients who met the inclusion criteria including patients' age more than 18 years and diagnosed with stroke. Patients with incomplete medical records or imaging data were excluded from the study. A total of 79 samples met the inclusion criteria for analysis following the sample size calculation.

2.4 Data collection

Demographic data including patients' age, gender, race, smoking status and clinical risk factors were retrieved from hospital records. Clinical risk factors include hypertension, diabetes mellitus, dyslipidaemia and atrial fibrillation. All data were organised using Microsoft Excel, and anonymisation was ensured by assigning each patient a unique identifier. Following the Malaysian Society of Neurosciences Guidelines, the age was categorised into four groups: 18–39 years, 40–59 years, 60–74 years and ≥ 75 years (Hamidon et al., 2021).

2.5 HU, lesion size and volume measurements

CT images were reviewed using Picture Archiving and Communication System (INFINTI PACS) with a standard brain window (window level; WL = 35 HU; window width; WW = 80 HU). Regions of interest were placed over hypodense (ischemic) or hyperdense (haemorrhagic) areas. HU values were quantified three times to improve the reliability of measurements, and the mean values were recorded.

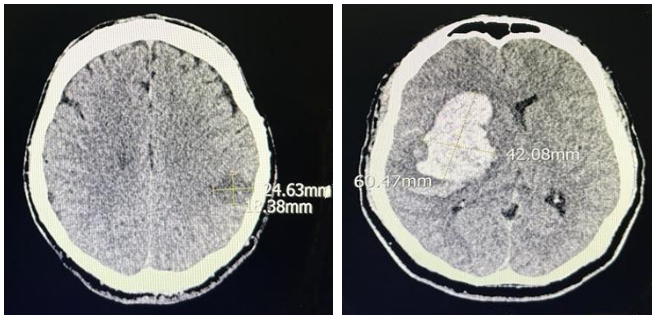
Stroke lesions were identified under supervision of a radiologist. As shown in Figure 1, for ischemic lesions, maximum orthogonal diameters were measured to determine the lesion size using the following formula (Kufner et al., 2020):

$$\text{Area} = A \times B$$

Meanwhile for haemorrhagic lesions, the volume was calculated using the following formula (Annongu et al., 2022):

$$\text{Volume} = (A \times B \times C) / 2$$

where A = transverse diameter, B = vertical diameter, C= total number of slides with the largest hematoma.



(a) (b)

Figure 1. (a) Size measurement of infarcted area in ischemic lesion and (b) haematoma volume in haemorrhagic lesion.

2.6 Statistical analysis

Descriptive statistics, independent t-tests and Pearson's correlation were employed to meet the objectives of the study. A p-value ≤ 0.05 was considered statistically significant. Data analysis was performed using SPSS version 27.

3. RESULTS AND DISCUSSION

3.1 Results

A total of 79 patients who met the inclusion criteria were analysed, comprising 38 males (48.1%) and 41 females (51.9%). The mean age of the study population was 65.27 ± 13.5 years. Females represented a slightly higher proportion (3.8% difference) compared to males. The age distribution showed that the highest incidence of stroke occurred in individuals aged 60 - 74 years (n = 31, 39.2%), followed by patients aged ≥75 years (n = 24, 30.4%). The lowest number of cases was observed in the 18 - 39 age group (n = 6, 7.6%). Malay patients constituted most of the study population (n = 73, 92.4%), followed by Chinese (n = 6, 7.6%), Indian (n = 1, 1.3%), and other ethnicities (n = 1, 1.3%) representing smaller proportions as shown in Table 3.1.

Table 3.1 Distribution of patient demographics in ischemic and haemorrhagic stroke.

	Ischemic n (%)	Haemorrhagic n (%)
Gender		
Male	35 (92.1)	3 (7.9)
Female	38 (92.7)	3 (7.3)
Age		
18 – 39	6 (100)	-
40 – 59	17 (94.4)	1 (5.6)
60 – 74	29 (93.5)	2 (6.5)
≥75	21 (87.5)	3 (12.5)
Ethnicity		
Malay	68 (93.2)	5 (6.8)
Chinese	4 (100)	-
Indian	-	1 (100)
Others	1 (100)	-

Hypertension was the most common clinical risk factor, present in 63 patients (79.7%), followed by diabetes mellitus in 42 patients (53.2%) and dyslipidaemia in 38 patients (48.1%). Smoking (n = 9, 11.4%) and atrial fibrillation (n = 6, 7.6%) were the least common risk factors. Out of the 79 confirmed stroke cases, 73 (92.4%) were ischemic and 6 (7.6%) were haemorrhagic, reflecting the well-established predominance of ischemic stroke in clinical populations.

A significant difference in mean HU values was found between ischemic and haemorrhagic strokes ($p = 0.01$; 95% CI: –53.74, –11.58). Ischemic lesions demonstrated markedly lower HU values (24.37 ± 5.91) compared to haemorrhagic lesions (57.17 ± 20.10), confirming the expected difference in tissue attenuation on CT imaging (Figure 2).

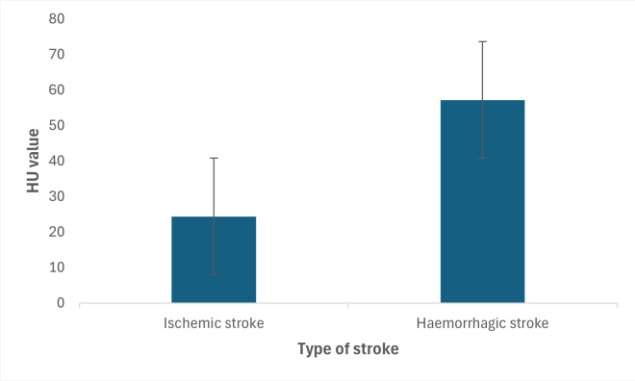


Figure 2. Mean HU values of ischemic stroke and haemorrhagic stroke.

Furthermore, Pearson correlation analysis demonstrated a weak and statistically insignificant correlation between lesion size and HU values ($r = – 0.198$, $p = 0.092$) in ischemic stroke. This suggests that HU reduction in ischemia may occur independently of lesion extent during the acute phase. Conversely, haemorrhagic lesions showed a strong and statistically significant positive correlation between HU values and lesion volume ($r = 0.829$, $p = 0.041$), indicating that larger haematomas tended to demonstrate higher HU values.

Overall, the findings support the utility and reliability of HU measurements in distinguishing stroke types and offer additional insights into lesion characteristics, particularly in haemorrhagic stroke.

3.2 Discussion

This study demonstrates that HU values obtained from non- contrast CT scans differ significantly between ischemic and haemorrhagic stroke, reinforcing the clinical value of HU quantification in acute stroke diagnosis. The results showed low HU values in ischemic lesions and markedly increased HU values in haemorrhagic lesions, consistent with established CT attenuation principles. Beyond confirming these differences, the study provides insights into the relationship between HU values, lesion characteristics, and patient clinical profiles. The findings of the present study align with previous literature, which reported mean HU values of approximately 18.9 HU in acute ischemic stroke lesions (Peng et al., 2024); 57.5 HU (Jeong et al., 2021) and 66.2–67.6 HU (Chen et al., 2022) in intracerebral haemorrhage; and 60–80 HU in acute haemorrhage (van Poppel, 2022). These established HU differences underpin the diagnostic distinction between haemorrhagic and ischemic stroke on non-contrast CT.

Low HU values in ischemic stroke are primarily attributed to increased water content resulting from cytotoxic and vasogenic oedema (Ajmani et al., 2023). During acute ischemia, failure of ATP-dependent ion pumps causes intracellular sodium and water influx, leading to tissue hypoattenuation (Sims & Muyderman, 2010). Zhu et al. (2021) reported that a 1% increase in water content reduces the HU value by approximately 1.8 HU, indicating a pattern reflected in our findings. Ischemic tissue demonstrates reduced cerebral blood flow, loss of grey–white differentiation and progressive infarction. These mechanisms explain the consistently low HU values observed in ischemic lesions in this study.

The absence of significant correlation between ischemic lesion size and HU values suggests that tissue density changes may occur independently of lesion extent during the acute and early subacute phases. This supports previous findings that early ischemic changes on non-contrast CT may appear subtle regardless of final infarct volume (Ospel et al., 2021), especially within the first 6 hours of onset.

Conversely, haemorrhagic strokes demonstrated significantly higher HU values, reflecting the intrinsic high attenuation of acute blood. HU increases proportionally with red blood cell concentration and haemoglobin content. The variability in HU values (wide SD ± 20.10) may be influenced by hematoma age, clot retraction (contraction), anaemia and serum extravasation, lowering HU values (Unnithan et al., 2023). Jeong et al. (2020) reported that clot contraction in the early hours of haemorrhage increases HU values as red blood cell packing intensifies. This aligns with the strong correlation observed between haemorrhagic lesion volume and HU, indicating that larger haematomas may manifest more extensive clot retraction or contain higher-density blood products. Our findings are consistent with the established radiological characteristics of stroke presenting hypodense and hyperdense on non-contrast CT in ischemic stroke and haemorrhagic stroke, respectively. This agreement strengthens the reliability of HU values as a diagnostic discriminant, particularly in settings lacking advanced imaging such as CT angiography or Magnetic Resonance Imaging (MRI).

The findings highlight several important clinical implications. Firstly, HU value is significant for enhanced diagnostic accuracy for the management of stroke patients. Radiographers and clinicians often rely on visual assessment

of non-contrast CT. Quantitative HU measurement improves objectivity and reduces diagnostic uncertainty, especially in early or subtle ischemia. Secondly, the HU value is valuable for rapid triage in emergency stroke pathways. HU-based differentiation is particularly valuable when MRI is unavailable or when CT perfusion is not routinely performed. In resource-limited or high-volume centres, HU quantification can assist in timely thrombolysis decisions. Thirdly, CT-based value is also significant as a prognostic information. Higher HU in haemorrhage has been associated with greater risk of haematoma expansion, increased mortality and poorer functional outcomes. Similarly, extreme low HU values in ischemia may indicate severe cytotoxic oedema and predict malignant infarction.

The demographic findings presenting higher stroke incidence among older adults and prevalence of hypertension and diabetes are consistent with national and global epidemiological patterns. The predominance of ischemic stroke (92.4%) aligns with the statistics by the Malaysian Society of Neurosciences, which has reported ischemic stroke as the most common subtype (Clinical Practice Guidelines: Management of Ischaemic Stroke, 2020). This study contributes to the growing literature on HU-based stroke evaluation. The findings provide local single centre-based Malaysian data on HU distributions in stroke patients and enhance the understanding of lesion density changes across stroke types.

There are several key limitations in this study. Firstly, the study was limited with small sample size for haemorrhagic stroke which restricting generalisation of the study population. The limited sample size restricts the stability of threshold-based analyses. Secondly, the single-centre design may not represent broader populations. Thirdly, there was absence of histopathology during data collection, which could improve biological interpretation. Future studies with larger and multi-centre stroke cohorts could be improved by several considerations which includes evaluating serial HU changes over time (e.g., hours to days), exploring HU thresholds predictive of clinical outcomes, combining imaging biomarkers with blood-based biomarkers and incorporating automated HU mapping software.

4. CONCLUSION

Haemorrhagic stroke presents significantly higher HU values than ischaemic stroke and correlated with the lesion volume. CT HU value is a potential imaging marker in differentiating ischemic from haemorrhagic stroke. This quantitative parameter may enhance diagnostic accuracy, especially in emergency settings where rapid decision-making is essential. Correlations between HU values and lesion volume further support their clinical utility.

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