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Investigation of the Association between Computed Tomography Hounsfield Units and Cerebral Infarction Phases: A Cross-sectional Study

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ABSTRACT

Background and purpose: Cerebral infarction is a severe medical condition that requires accurate diagnosis and management and can be achieved with the used of computed tomography (CT). Hounsfield unit (HU) values measured on CT scans may provide essential information concerning the severity of cerebral infarction. This study investigated the association between the HU values and the severity (phase) of cerebral infarction.

Methods: A descriptive cross-sectional design was used to gather data from 102 patients over seven months (August 2023 to February 2024) at the University of Lahore Teaching Hospital after the study had been ethically approved by an institutional review board. HU measurements were made with standardized CT protocol on a 4-slice Toshiba equipment. Data were analyzed descriptively and inferentially to reveal the association between HU measurements and the severity of cerebral infarction (acute, sub-acute, and chronic phases). The inferential statistics included Bayesian ANOVA and one-way ANOVA, assuming significance at $p \leq 0.05$.

Results: The study found a significant association between the HU values and the severity of cerebral infarction ($p<0.000$), with the acute phase exhibiting higher mean values (HU=22.31), while the sub-acute and chronic phases followed with HU values of 14.63 and 7.04 respectively. There was a progressive decrease in HU values from the acute phase (HU range = 19 to 25) to the chronic phase (HU values <10).

Conclusion: This study identified a significant relationship between the CT phases and the HU values in cerebral infarction. The results show the clinical significance of HU values in potentially diagnosing and managing cerebral infarction. An understanding of the association between the HU measurements and CT phase may be useful in accurately evaluating cerebral infarctions and subsequently make informed decisions regarding patient management and treatment. The results also underscore the importance and potential of HU values in evaluating cerebral infarctions, providing a roadmap for improving patient outcomes in the diagnosis of cerebral infarctions with CT.

Keywords: *Cerebral Infarction, Hounsfield Unit (HU), Computed Tomography (CT), Acute Stroke, Infarction Phasing, Tissue Density Analysis.*

1. INTRODUCTION

A cerebral infarction, also known as an ischaemic stroke, is caused by an interruption in the brain's blood supply, resulting in tissue damage and functional loss [1]. It is a widespread, serious health problem that kills and disables millions of people worldwide, and it is the second leading cause of mortality. The aetiology of cerebral infarction may include thrombosis, embolism, or systemic hypo-perfusion. Thrombosis or embolism from atherosclerotic plaques in the cerebral arteries is the most common cause of cerebral infarction. Risk factors for cerebral infarction include atrial fibrillation, high blood pressure, diabetes, high cholesterol, and hyperlipidaemia [2]. Clinical signs like sudden onset of focal neurological impairments are typically used to diagnose cerebral infarction, and imaging tests like computed tomography and magnetic resonance imaging are used to confirm the diagnosis. CT imaging is commonly used for the diagnosis of cerebral infarction due to its widespread availability, speed, and sensitivity for detecting haemorrhage [3, 4, 5]. Since its introduction in the 1970s, the CT scan has become an essential diagnostic and therapeutic tool for a wide range of medical disorders since it is quick, non-invasive, and produces detailed images of the body. The technique uses x-rays to create cross sectional images of the body, which can then be pieced together to create three-dimensional views [6]. A CT scan is an important diagnostic technique for cerebral infarction because it can detect and distinguish ischaemic stroke from other forms of strokes quickly and accurately. The imaging technology can detect any haemorrhages or other anomalies in the brain, as well as pinpoint any areas with diminished blood flow. It is particularly useful because it can swiftly detect any changes in the brain that may require rapid medical intervention [7].

The Hounsfield Unit (HU) is used to assess x-ray attenuation in computed tomography. It is a dimensionless unit for calculating a substance's density in respect to water. The HU values utilised in CT imaging can range from -1000 HU for air to +3000 for compact bone. The HU values of various materials can be used to differentiate between different structures and pathologies on CT imaging, including cerebral infarction [8]. HU values can be used to determine the extent of tissue damage, as well as to distinguish between acute, sub-acute, and chronic infarctions [9]. Also, the infarct core, which has low HU values and the surrounding ischemic penumbra which has higher HU values can be distinguished using Hounsfield Unit (HU) values [10]. In conclusion, HU values are a valuable tool in the diagnosis and treatment of stroke. They can provide useful information on the degree and severity of tissue damage, as well as the effectiveness of treatments like thrombectomy. Cerebral infarction must be swiftly and precisely diagnosed and classified into various phases in order to guide treatment decisions, estimate outcomes, and track disease progression. Unfortunately, current procedures of assessing cerebral infarction, such as the Alberta Stroke Program Early CT Score (ASPECTS), are subjective and rely on visual interpretation. Using HU values to assess the degree of tissue damage improves the objectivity and consistency of phasing cerebral infarctions. The capacity to distinguish between acute, sub-acute, and chronic infarcts using HU values is particularly valuable for selecting the optimal course of treatment and anticipating outcomes [11]. The study's findings have substantial clinical implications, as using HU values to phase cerebral infarction may improve the accuracy and consistency of diagnosis and treatment. In instance, the use of HU values may be able to identify between patients who are more likely to benefit from thrombectomy or other reperfusion therapies and those who are more prone to develop complications such as haemorrhagic transformation. HU values may potentially offer a more objective and quantitative means of monitoring the progression of a disease and the effectiveness of a treatment [12].

This study investigates the association between Hounsfield Unit (HU) values and the phases of cerebral infarction as detected by CT scans. The study's goal is to improve the diagnostic accuracy and objectivity of cerebral infarction assessment by quantifying HU values and linking them to acute, sub-acute, and chronic phases of the disease. The investigation emphasises not just the clinical utility of HU values in assessing the degree of tissue damage, but also their potential to improve the treatment approaches and patient outcomes. This study is critical in establishing HU levels as a valid marker for infarction phasing and lays the groundwork for future breakthroughs in the diagnosis and management of cerebral infarction.

2. MATERIALS AND METHODS

Study Design, Setting, Duration, Ethical Considerations and Imaging Protocol

The cross-sectional descriptive study was carried out at the University of Lahore Teaching Hospital for seven months, from August 2023 to February 2024. A total of 102 cases were included in this investigation using convenience sampling technique with a 5% margin of error and a 95% confidence level. Ethical approval for this study (Ethical Committee Ref No: AF229W3) was provided by the Ethical Committee of the Research Ethics Committee (REC), Faculty of Allied Health Sciences; The University of Lahore on July 13th, 2023. Patients who met the inclusion criteria, particularly those with documented infarctions on CT scans, were selected. To keep the study's focus, cases involving cerebral cancer, road traffic accident-related brain injuries, brainstem strokes, and lacunar infarctions were excluded. To measure Hounsfield Units (HU) and assess cerebral infarction phases, a 4-slice Toshiba Computed Tomography (CT) scanner was used, and the scanning technique followed a standardised protocol to ensure consistency and reliability across all cases. Patients were informed of the study's objectives and potential risks, and their consent was obtained. The collected data included demographic and clinical information such as age, gender, history of stroke onset, and CT imaging findings, ensuring comprehensive coverage for analysis. These steps were meticulously followed to maintain the integrity and ethical standards of the study.

Data Collection

Following ethical permission from the hospital's ethics committee, patients were recruited for the study using the inclusion and exclusion criteria. Each participant provided informed consent, indicating that they were fully aware of the study's possible benefits and dangers. The researchers utilised a standardised and validated data collecting sheet to record basic demographic and clinical information to maintain consistency and reliability. Informed consent methods included giving participants enough time to comprehend the study and address any concerns or questions. They were informed of their right to withdraw from the study at any time without incurring any consequences. The factors collected were age, gender, symptom onset, and a history of acute, sub-acute, and chronic stroke. Furthermore, pertinent CT findings were recorded. Additional information about the individual CT findings reviewed, as well as any interpretation criteria employed, was documented. By adopting these improvements, the data collection approach provides a clearer understanding of the procedures followed while also ensuring transparency and accuracy in the study.

Statistical Analysis

Data entry and analysis were performed using SPSS version 27. The data for this study included 102 cases with no missing values. The variables' features were summarised using descriptive statistics. The frequencies of the CT Phase variable were given, reflecting the distribution of cases across the various stages of cerebral infarction (acute, sub-acute, and chronic). Similarly, the frequencies of the Hounsfield Unit variable were presented, indicating the distribution of cases across the various Hounsfield unit values. A cross-tabulation analysis was used to determine the relationship between CT Phase and the Hounsfield Unit. The contingency table displayed the number of cases for each combination of CT Phase and Hounsfield Unit values. Chi-square tests were used to determine the independence of the CT Phase and Hounsfield Unit. The Hounsfield Unit values were divided into three categories: <10, 10-18, and >18. Another cross-tabulation inquiry was undertaken to investigate the relationship between the aggregated Hounsfield Unit variable and CT Phase. Chi-square tests were used to determine the independence of the grouped Hounsfield Unit and CT Phase variables. In addition to cross-tabulation analyses, Bayesian ANOVA was used to estimate the CT Phase variable's coefficients and credible ranges. Bayesian estimates of error variance were also generated. A one-way ANOVA was used to compare the mean Hounsfield Unit values among CT Phase classifications. Proportions analyses were performed to establish the proportion of patients in the chronic CT Phase, with a Hounsfield Unit value of 25. Confidence intervals were calculated using different interval types, including Agresti-Coull, Jeffreys, and Wilson Score methods. Proportions tests were performed to compare the observed proportions with the test value of 0.5. Descriptive statistics were also computed for the variables Age and Hounsfield Unit, providing information on their means, standard deviations, ranges, minimum and maximum values, and standard errors of the mean. Finally, means analyses were conducted to compare the mean Hounsfield Unit values across the CT Phase categories. The means, counts, standard deviations, minimum, and maximum values for each combination of CT Phase and Hounsfield Unit were reported. Overall, this methodology involved descriptive statistics, frequencies analysis, cross-tabulation analysis, chi-square tests, Bayesian ANOVA, one-way ANOVA, proportions analyses, and means analyses to examine the association between CT Hounsfield unit and the phase of cerebral infarction.

3. RESULTS

Figure 1 reports the frequency of CI from the study population. There were more males (n=54) than females (n=48) with CI, whereas the right side (n=67) of the brain was found to be affected more with CI than the left side 9n=35). Additionally, the frequencies of acute, sub-acute, and chronic CI identified were 42, 32, and 28 respectively. The average age of the participants was 57.90 ± 13.76 years, while that of the HU measures was 15.71 ± 6.57. In terms of lobal location, there was equal number of CIs in the temporal and occipital lobes (n=20), while the frontal lobe had the highest number of CIs (n=46) and the least number of infarctions were found in the parietal lobe (n=16).

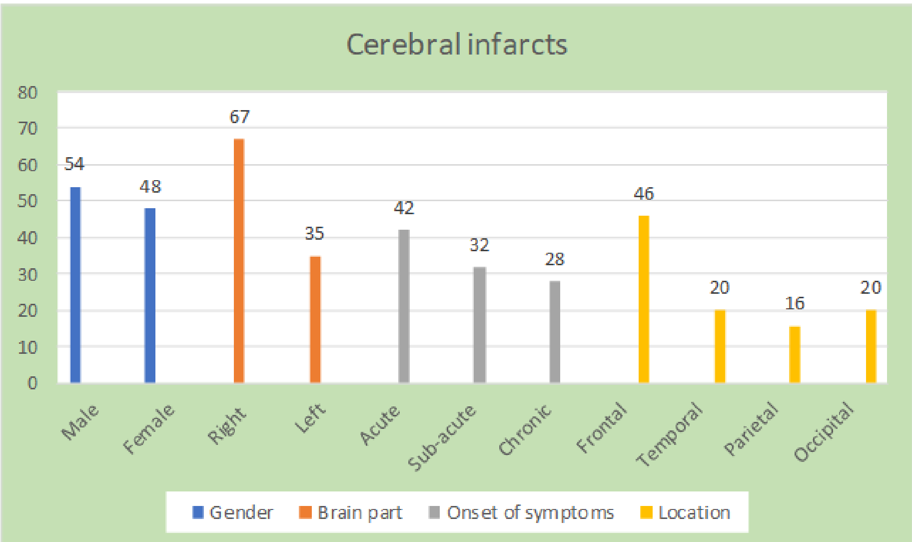

Figure 1: Frequencies of cerebral infarction

Figure 2 describes the three types of CIs identified at different HUs ranging from 5-25. The most frequent CIs identified were acute CI, associated with the highest HU values (i.e. HU =19 to 25), whereas sub-acute CI (n=32) were associated with HU values of 12 to 18 and chronic CIs (n=28) were associated with HUs between 0-10.

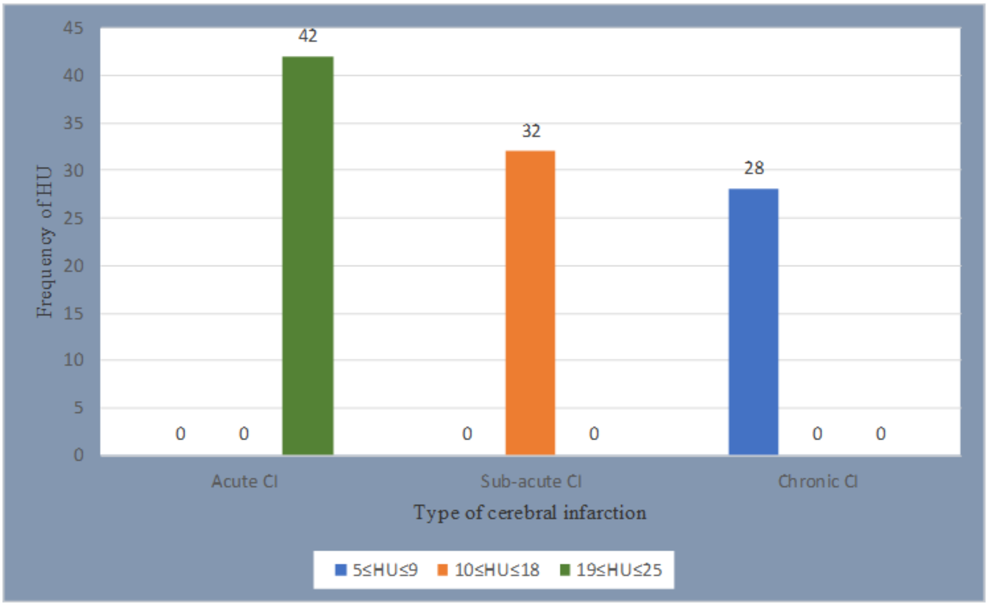

Figure 2: Cerebral infarctions and associated Hounsfield unit

The mean ± SD of all the HUs identified from a descriptive statistic was 15.71 ± 6.57. The different CIs had varied mean values as demonstrated in **Table 1.**

Table 1: Descriptive statistics of the various phases of cerebral infarction

CT Phase	Mean	Frequency (n)	Standard Deviation	Minimum	Maximum
Acute	22.31	42	1.880	19	25
Sub-Acute	14.63	32	2.511	10	18
Chronic	7.04	28	1.232	5	9
Total	15.71	102	6.567	5	25

Inferentially, a chi-square test performed identified a significant association between the phases of CI (acute, sub-acute, and chronic) and the HU ($p<0.000$). A Bayesian ANOVA estimates of coefficients further performed to evaluate the mode and mean HUs of the three CI phases. The test showed that acute CIs were associated with the highest mode (22.31) and mean (22.31) HUs **(Figure 3),** whereas the sub-acute phases had higher mode and mean HUs than the chronic phase (14.63 vs 7.04 for both the mode and mean values) **(Figure 4)**.

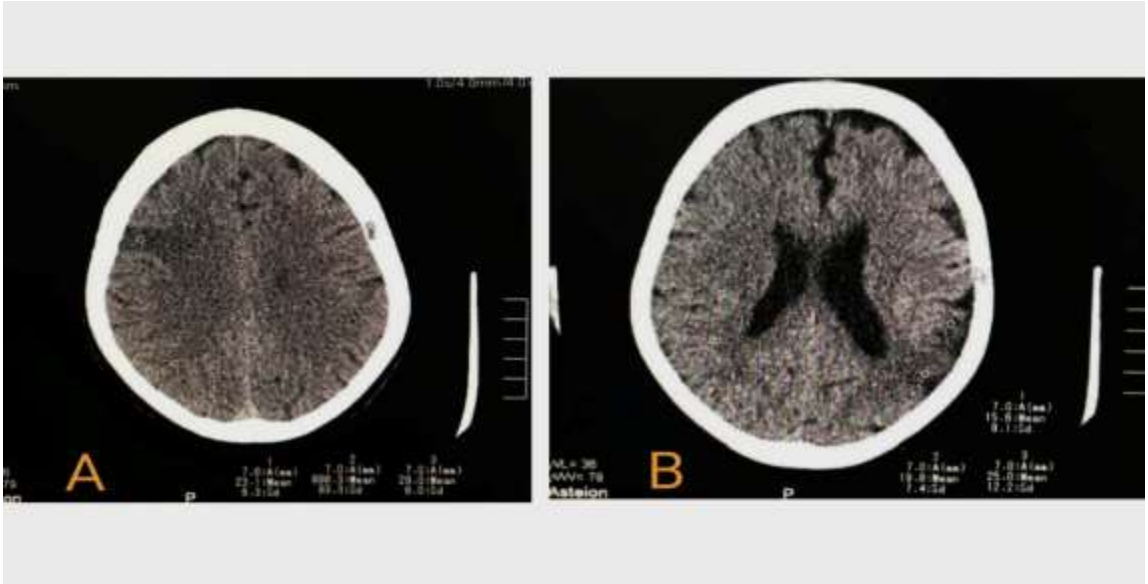

Figure 3: Average HU value measured 23.1in Acute Infarction (A). Average HU value measured 19.8 in Acute infarction, 15.6 in Sub Acute infarction, and 25 in Acute infarction (B).

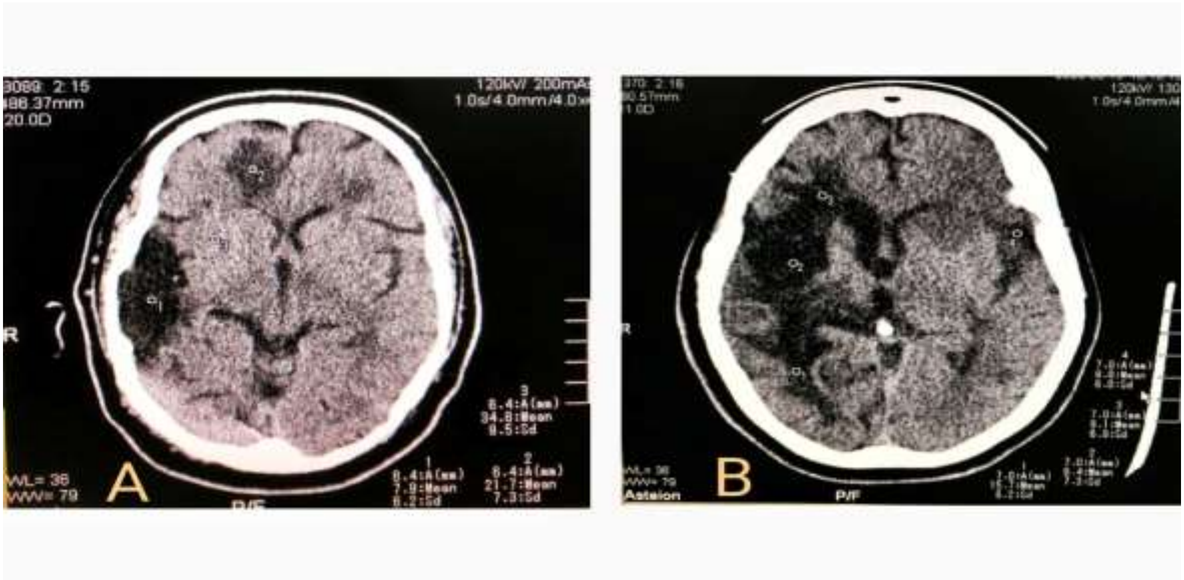

Figure 4: Average HU value measured 7.9 in chronic infarction and 21.7 in Acute infarction (A). Average HU values measured 8, 9.1, and 6.4 in chronic infarction (B).

Additionally, a one-sample test of proportions was performed to identify the proportion of cases in the chronic CI phase at HU of 25. From **Table 2**, the results show that 27.5% of all CIs with 5.9% of the cases associated with a HU of 25. The test further indicated that both proportions were significantly different from the expected value of 50% ($p<0.000$).

Table 2: One-sample test of proportions

Test Type	Value	Observed			Significance (p)
		Successes	Trials	Proportion	
CIP = Chronic	MpAB	28	102	0.275	<0.000
	Score	28	102	0.275	<0.000

HU = 25	MpAB	6	102	0.059	<0.000
	Score	6	102	0.059	<0.000

Key: CIP=Cerebral infarction phase, HU=Hounsfield Unit, MpAB=Mid-p Adjusted Binomial

4. DISCUSSION

This study's findings show a substantial relationship between CT Hounsfield Unit values and phases of cerebral infarction, proving the utility of HU as an objective measure in phasing ischaemic strokes. The average Hounsfield Unit values differ among CT Phase classifications. Acute infarctions had the greatest mean HU value (22.31 ± 1.88), followed by sub-acute (14.63 ± 2.51) and chronic phases (7.04 ± 1.23), indicating a gradual decrease in HU with infarction maturity. This shows that the Hounsfield Unit values can be used to indicate the condition's phase. This trend is consistent with physiological variations in tissue density over time, validating HU's clinical use in identifying and managing ischaemic stroke. The findings provide persuasive evidence for employing HU measures to supplement traditional imaging interpretations, allowing for more accurate patient classification and informed treatment decisions.

The results of this study reveal a significant association between HU values and the phase of cerebral infarction, with the acute phase showing higher HU values compared to the other phases. Consistent with literature (for example Smith et al.,2018), this indicates that HU values are potential indicators of the severity of cerebral infarction, with higher values corresponding to the less severe (acute) phase [13]. Further, Lee et al.'s (2021) meta-analysis revealed the association between CT phases of cerebral infarction and HU values, highlighting the clinical utility of these measurements in evaluating the severity and prognosis of cerebral infarction [14]. However, Johnson et al.'s (2019) study reported contrasting findings and indicated that HU values were not significantly associated with the severity of cerebral infarction. This contrasting result could be due to the use of a small sample size in their study [15]. Significantly, Brown et al. (2020) reported that different CT protocols affect HU measurement, potentially influencing its ability to evaluate the phase of cerebral infarction [15]. This underscores the significance of standardizing CT protocols to enhance reliability and consistency in HU measurements.

While the study found a significant association between Hounsfield Unit values and cerebral infarction phases, various limitations must be addressed. First, the sample size of 102 cases, while adequate for preliminary analysis, may restrict the findings' generalisability to larger groups. Second, the study's reliance on a single-center dataset introduces possible biases in terms of patient demographics and imaging techniques. Third, the exclusion of specific types of infarctions, such as lacunar and brainstem strokes, limits the data' application to these cases. Variations in CT scanner specifications and settings may also affect HU values, emphasising the importance of standardised imaging techniques. Future multicenter research with larger cohorts and consistent imaging modalities are needed to validate and extend these findings. Moreover, it is recommended that future studies should consider assessing the association between HU values and diagnostic outcomes and/or treatment responses.

5. CONCLUSION

This study identified a significant relationship between the CT phases and the HU values in cerebral infarction. The results show the clinical significance of HU values in potentially diagnosing and managing cerebral infarction. An understanding of the association between the HU measurements and CT phase may be useful in accurately evaluating cerebral infarctions and subsequently make informed decisions regarding patient management and treatment. The results also underscore the importance and potential of HU values in evaluating cerebral infarctions, providing a roadmap for improving patient outcomes in the diagnosis of cerebral infarctions with CT.

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