Computed tomography perfusion in acute ischemic stroke: Correlation of perfusion findings with follow-up imaging after intravenous thrombolysis

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Компютърнотомографска перфузия при остър исхемичен мозъчен инсулт: корелация между перфузионните находки и проследяващите образни изследвания след интравенозна тромболиза

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Abstract:

Background: Acute ischemic stroke (AIS) is a leading cause of morbidity and mortality worldwide, characterized by a sudden interruption of cerebral blood flow and rapid neuronal injury. Early differentiation between the infarct core and ischemic penumbra is critical for appropriate therapeutic decision-making. **Aim:** To evaluate the role of computed tomography perfusion (CTP) imaging in evaluating brain tissue viability and predicting imaging outcomes after intravenous thrombolytic therapy in patients with acute ischemic stroke. **Materials and Methods:** Four representative patients with acute ischemic stroke who underwent CT perfusion imaging prior to intravenous thrombolysis at Heart and Brain Hospital, Burgas, were retrospectively reviewed. Perfusion parameters, including cerebral blood flow (CBF), cerebral blood volume (CBV), mean transit time (MTT), and time to maximum (Tmax) were analyzed and correlated with 24-hour follow-up CT findings. **Results:** Patients with a predominance of ischemic penumbra and minimal infarct core demonstrated favorable imaging outcomes after thrombolysis, whereas large infarct cores were associated with extensive infarction or hemorrhagic transformation on follow-up imaging. **Conclusion:** CT perfusion is a valuable tool in the diagnostic and therapeutic workflow of acute ischemic stroke, allowing individualized treatment strategies and improving clinical outcomes through the precise identification of viable brain tissue.

Key words: acute ischemic stroke, CT perfusion, infarct core, penumbra, thrombolysis

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Резюме:

Увод: Острият исхемичен мозъчен инсулт (ОИМИ) е една от водещите причини за заболяемост и смъртност в световен мащаб, характеризираща се с внезапно прекъсване на мозъчния кръвоток и бързо увреждане на невроните. Ранното разграничаване между инфарктното ядро и исхемичната пенумбра е от съществено значение за правилното терапевтично поведение. **Цел:** Да се оцени ролята на компютърнотомографската перфузия (КТ перфузия) при определяне жизнеспособността на мозъчната тъкан и прогнозиране на образния изход след интравенозна тромболитична терапия при пациенти с остър исхемичен мозъчен инсулт. **Материал и методи:** Ретроспективно бяха анализирани четири представителни случая на пациенти с остър исхемичен мозъчен инсулт, при които е проведено КТ перфузионно изследване преди интравенозна тромболиза в МБАЛ "Сърце и мозък" – Бургас. Анализирани бяха перфузионните показатели: мозъчен кръвоток (CBF), мозъчен кръвен обем (CBV), средно време на транзит (MTT) и време до максимум (Tmax), като резултатите бяха съпоставени с контролните КТ изследвания, извършени 24 часа след тромболизата. **Резултати:** Пациентите с преобладаваща исхемична пенумбра и минимално или липсващо исхемично ядро показаха благоприятен образен изход

след проведената тромболиза, докато по-големите инфарктни ядра бяха свързани с развитието на обширен мозъчен инсулт или хеморагична трансформация при проследяващи образни изследвания. **Заключение:** КТ перфузията е ценен метод в диагностичния и терапевтичния алгоритъм при остър исхемичен мозъчен инсулт, като позволява индивидуализиране на лечебната стратегия и подобрява клиничния изход чрез прецизно определяне на жизнеспособна мозъчна тъкан.

Ключови думи: остър исхемичен мозъчен инсулт, КТ перфузия, тромболиза

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Introduction

Acute ischemic stroke (AIS) occurs due to insufficient supply of oxygen and nutrients to brain tissue, most commonly caused by thrombotic or embolic arterial occlusion [1]. It remains a leading cause of disability and mortality in developed countries [2].

In recent years, nearly 12 million stroke cases have been reported worldwide, with national statistics in Bulgaria reflecting similar trends, with over 13,000 cases of acute cerebrovascular disease annually [2, 3]. High mortality rates and severe long-term complications persist, including motor, cognitive, and speech impairments [2].

Imaging plays a central role in the diagnostic pathway of AIS. Non-contrast computed tomography (NCCT) is considered the gold standard initial imaging modality for differentiating ischemic from hemorrhagic stroke [4]. It provides essential information regarding lesion location, size, and eligibility for reperfusion therapy. However, NCCT has limitations, particularly in the early detection of ischemic changes, as up to 60% of infarcts become visible only between the 3rd and 6th hour after symptom onset [5]. The Alberta Stroke Program Early CT Score (ASPECTS) is commonly used to assess early ischemic changes, particularly loss of gray-white matter differentiation in the territory of the middle cerebral artery [5].

Despite its value, conventional CT imaging cannot reliably determine the presence of salvageable brain tissue. This limitation is addressed by CT perfusion (CTP), which provides critical information regarding cerebral hemodynamics and allows differentiation between infarct and ischemic penumbra [6]. Given the principle that “time is brain”, rapid diagnosis and timely reperfusion are essential for preserving viable tissue and improving clinical outcomes [7].

Materials and Methods

This case series includes four representative patients with acute ischemic stroke who underwent CT perfusion imaging, followed by intravenous thrombolytic therapy at Heart and Brain Hospital, Burgas. Follow-up imaging studies were evaluated to determine therapeutic effectiveness and the presence of complications.

CT Perfusion Principles and Quantitative Parameters

CT perfusion (CTP) imaging enables dynamic evaluation of cerebral hemodynamics by tracking the passage of intravenously administered contrast material through the brain parenchyma. This technique provides both qualitative and quantitative assessment of cerebral perfusion, allowing accurate differentiation between infarct core and ischemic penumbra, which is critical for therapeutic decision-making.

Perfusion data are processed using dedicated software platforms such as Philips IntelliSpace Portal, which generates standardized perfusion maps and applies validated thresholds for tissue classification.

Several key parameters are analyzed.

● Mean Transit Time (MTT) reflects the average time required for blood to traverse the capillary network and is typically prolonged in ischemic regions.

● Time to Peak (TTP) represents the time to maximum contrast enhancement and provides indirect information about arterial inflow.

● Time to Maximum (Tmax) is a delay-sensitive parameter and one of the most reliable indicators of hypoperfusion. A Tmax delay greater than 6 seconds is generally considered indicative of critically hypoperfused tissue (ischemic penumbra), while values exceeding 10 seconds are associated with a high probability of progression to infarction [8, 9].

● Cerebral Blood Flow (CBF) reflects the rate of blood delivery to brain tissue and is a primary parameter for defining the infarct core. A reduction of CBF to less than 30% of normal values is widely accepted as a threshold for irreversible ischemic damage [10].

Based on these parameters, automated software algorithms generate volumetric maps distinguishing infarct core from penumbra, enabling rapid and objective assessment. The mismatch between hypop-

erfused tissue (Tmax > 6s) and infarct core (CBF < 30%) is used to identify patients who are likely to benefit from reperfusion therapy [10, 11].

This quantitative, tissue-based approach has become fundamental in modern stroke imaging, allowing extension of treatment indications beyond the traditional time window and supporting individualized patient management [12].

Imaging Protocol

CT perfusion studies were performed using a 64-slice multidetector CT scanner (Philips Incisive, Philips Healthcare). All examinations were conducted according to a standardized institutional stroke imaging protocol.

A bolus of approximately 50 mL of iodinated contrast agent was administered intravenously at a flow rate of 5.5 mL/s, followed by a saline flush of approximately 20 mL to ensure optimal contrast delivery. Dynamic scanning of the neurocranium was initiated with minimal delay after contrast injection and continued for a duration of 45-60 seconds to capture the full passage of contrast through the cerebral circulation. The acquired imaging volume covered approximately 8-10 cm along the z- axis, including the basal ganglia and supraganglionic regions. The selection of the scanned region was adjusted when necessary based on the clinical presentation and suspected vascular territory involved.

Post-processing of perfusion data was performed using dedicated software, generating quantitative maps of cerebral perfusion parameters. Initial analysis focused on time-based parameters, including mean transit time (MTT), time to peak (TTP), and time to maximum (Tmax), which are typically prolonged in ischemic regions and reflect disturbances in cerebral blood flow dynamics.

Clinical Cases

A total of four representative clinical cases were analyzed to illustrate the practical application of CT perfusion in acute ischemic stroke (Table 1).

An 88-year-old male presented with right-sided weakness and aphasia. Non-contrast CT (NCCT) revealed no early ischemic changes (ASPECTS=9). CT perfusion demonstrated an extensive area of hypoperfusion in the left middle cerebral artery (MCA) territory, consistent with an ischemic penumbra in M5 segment and no infarct core (Fig. 1). On 24-hour follow-up imaging after thrombolysis, NCCT showed no development of infarction (Fig. 2).

Table 1. Summary of the presented cases

Case	Age	ASPECTS	Penumbra	Infarct Core	Follow-up CT Findings
1	88	9	100%	0%	No infarction
2	71	9	90%	10%	Small basal ganglia infarction
3	84	9	100%	0%	Hemorrhagic transformation
4	92	8	62%	38%	Large MCA infarction

Fig. 1. Non-contrast CT and perfusion maps (MTT, TTP, CBV and CBF) demonstrating a focal area of hypoperfusion in the left M5 segment, characterized by prolonged mean transit time and time to peak, with preserved cerebral blood volume, suggestive of ischemic penumbra

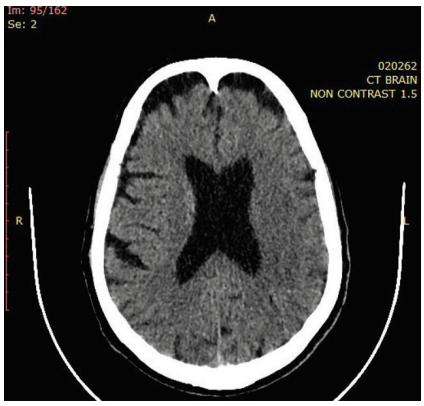

Fig. 2. On the 24-hour follow-up computed tomography after thrombolysis, there is no development of infarction

A 71-year-old female presented with left-sided weakness after awakening. NCCT showed hypodensity in the area of the basal ganglia on the right side with blurring of the outline of the putamen (ASPECTS=9). On CT perfusion,a large area of hypoperfusion is established in the basin of the right MCA, with an ischemic penumbra 90% and infarct core 10% (Fig. 3). Follow-up imaging at 24-hour after thrombolysis revealed a small infarction in the right basal ganglia (Fig. 4).

An 84-year-old female presented with right-sided weakness and aphasia. NCCT demonstrated early ischemic changes (ASPECTS=9) in the left MCA territory. CT perfusion revealed a 100% penumbra and no infarct core (Fig. 5). On the next day after 24-hour follow-up, CT shows intraparenchymal hemorrhage in the left basal ganglia (Fig. 6).

A 92-year-old patient presented with left-sided weakness. NCCT showed early ischemic changes (ASPECTS=8). CT perfusion demonstrated hypoperfusion with approximately 62% penumbra and 38% infarct core (Fig. 7). Follow-up imaging revealed a large infarction in the right MCA territory (Fig. 8).

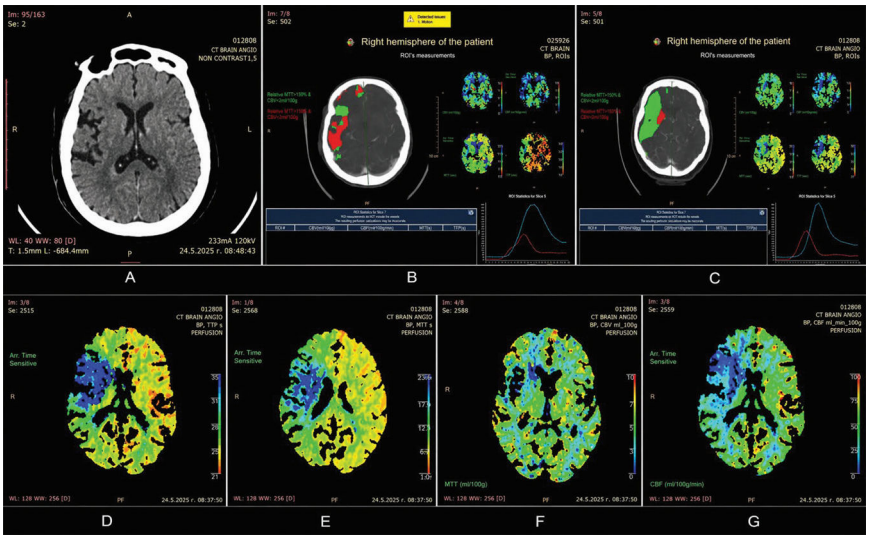

Fig. 3. Brain CT and perfusion imaging. Non-contrast CT without clear early ischemic changes (A). Perfusion maps (B-G) MTT, TTP, CBV and CBF demonstrating prolonged transit time and reduced cerebral blood flow with relatively preserved blood volume in the right hemisphere, consistent with perfusion mismatch and ischemic penumbra and infarct core

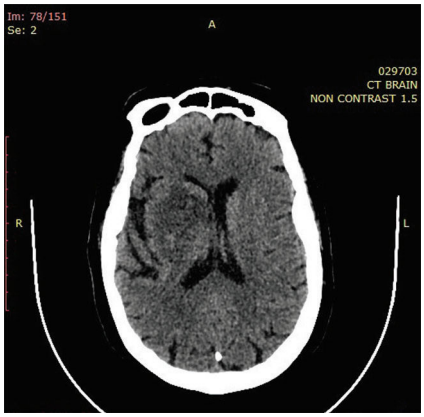

Fig. 4. On the 24-hour follow-up CT after thrombolysis, there is a small infarction in the right basal ganglia

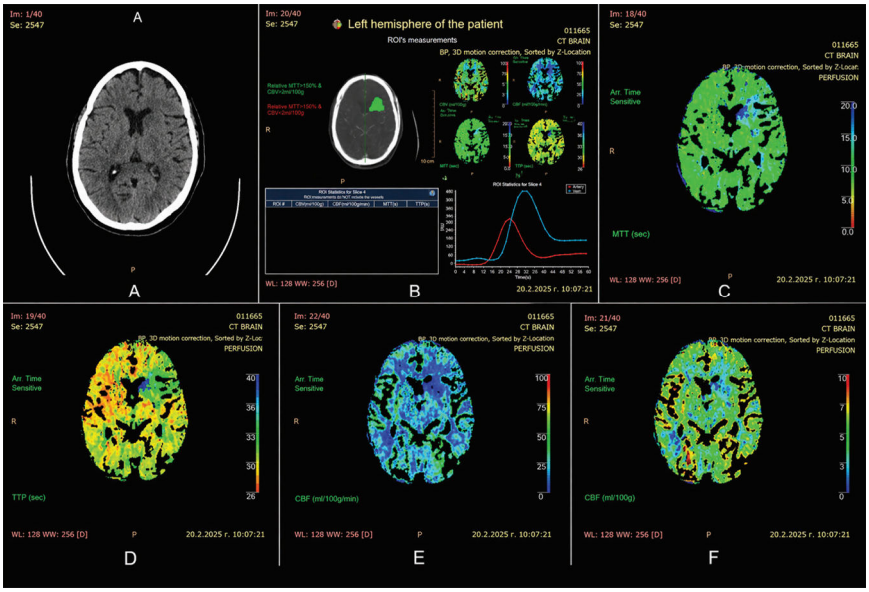

Fig. 5. Non-contrast CT (A) and perfusion maps (B-F) demonstrating ischemic changes in the left basal ganglia. Perfusion maps show prolonged MTT and TTP with reduced CBF and relatively preserved CBV, consistent with ischemic penumbra

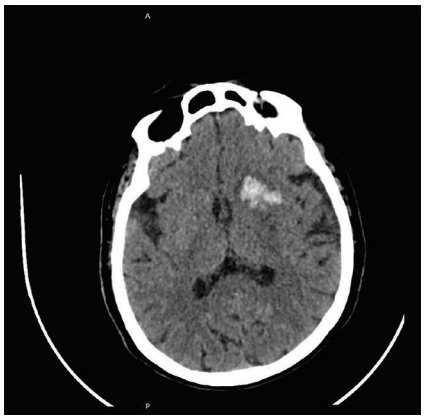

Fig. 6. A 24-hour follow-up non-contrast CT scan after thrombolysis demonstrated a small hemorrhagic area in the left basal ganglia

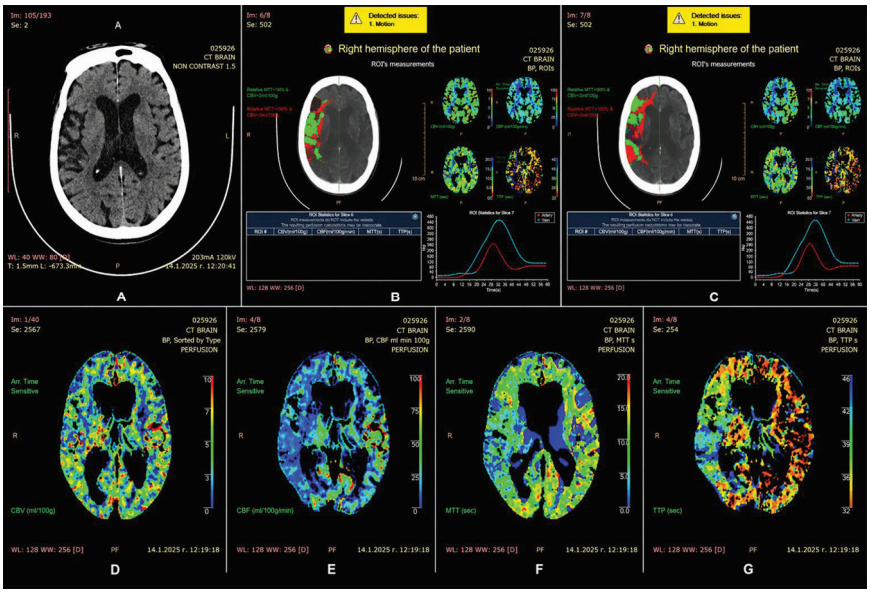

Fig. 7. Non-contrast CT (A) and perfusion maps (B-G) demonstrating ischemic changes in the right MCA territory. Perfusion maps show prolonged MTT and reduced CBV, with decreased cerebral blood flow. Findings are consistent with ischemic penumbra and infarct core

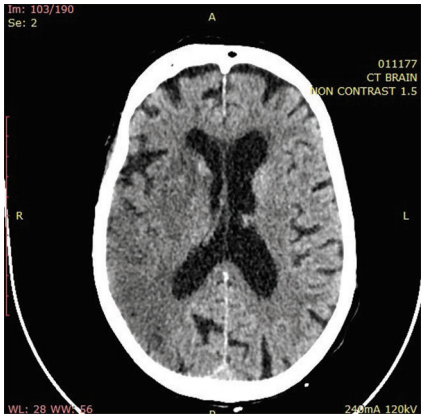

Fig. 8. Non-contrast follow-up CT after 24-hour demonstrating large ischemic infarction in the right MCA territory

Results

The main clinical and imaging characteristics of the presented patients are summarized in Table 1.

In the presented cases, CT perfusion findings demonstrated good correlation with subsequent imaging evolution after intravenous thrombolytic therapy. Two patients with a predominance of ischemic penumbra and minimal or absent infarct core (Cases 1 and 2) showed favorable outcomes on follow-up CT examinations. In the first patient (88 years old, ASPECTS=9), CT perfusion demonstrated 100% ischemic penumbra without evidence of an infarct core, and no infarction developed on the 24-hour follow-up CT. Similarly, the second patient (71 years old, ASPECTS=9), with 90% penumbra and only 10% infarct core, developed only a small infarction in the right basal ganglia on follow-up imaging.

In some patients, the initial non-contrast CT study showed either very subtle abnormalities or no definite early ischemic changes, while CT perfusion already demonstrated significant disturbances of cerebral perfusion. This additional information proved particularly valuable during the hyperacute stage, when rapid therapeutic decision-making was required.

Less favorable follow-up findings were observed in patients with larger infarct core volumes or more advanced ischemic injury. The third patient (84 years old, ASPECTS=9), despite demonstrating complete perfusion mismatch with 100% penumbra and no measurable infarct core, developed hemorrhagic transformation following thrombolytic therapy. The fourth patient (92 years old, ASPECTS=8) showed a substantial infarct core (38%) and a smaller proportion of salvageable tissue (62% penumbra), with follow-up CT revealing a large infarction in the right middle cerebral artery territory.

Overall, the presented cases illustrate the practical value of CT perfusion in estimating tissue viability, identifying ischemic penumbra, predicting imaging outcomes, and supporting individualized therapeutic decision-making in patients with acute ischemic stroke.

Discussion

The present study demonstrates the practical value of CT perfusion imaging in the evaluation of patients with acute ischemic stroke, particularly in situations where non-contrast CT findings are subtle or inconclusive [13]. In several of the presented patients, NCCT showed either minimal early ischemic changes or no definite abnormalities, while perfusion imaging clearly demonstrated areas of hypoperfusion corresponding to ischemic penumbra. This allowed rapid therapeutic decision-making and appropriate patient selection for thrombolytic therapy [14]. Similar observations have been reported by Halil et al., who demonstrated the value of CT perfusion in identifying candidates for intravenous thrombolysis based on the extent to ischemic penumbra and infarct core [15].

An important observation in our series was the relationship between perfusion mismatch and follow-up

imaging findings. Patients with a large volume of salvageable tissue and a relatively small infarct core generally demonstrated more favorable imaging evolution after thrombolysis. In some cases, no definite infarction developed on 24-hour follow-up CT despite the presence of extensive perfusion abnormalities on initial examination. Conversely, patients with a larger infarct core and more advanced ischemic injury demonstrated less favorable outcomes and a higher risk of extensive infarction or hemorrhagic transformation [16].

The presented cases also illustrate the limitations of relying exclusively on conventional CT imaging in the hyperacute stage of stroke. Although NCCT remains essential for excluding intracranial hemorrhage and assessing early ischemic changes, it cannot reliably determine tissue viability. CT perfusion provides additional functional information regarding cerebral hemodynamics and allows differentiation between irreversibly damaged tissue and potentially salvageable brain parenchyma [16, 17].

In our clinical practice, parameters such as Tmax, CBF, and CBV proved particularly useful for evaluating the extent and severity of perfusion disturbances. Delayed Tmax and prolonged MTT were consistently associated with hypoperfused tissue, whereas marked reductions in CBF and CBV correlated with the infarct core. These findings are consistent with currently accepted perfusion thresholds used in modern stroke imaging protocols [17].

Another important aspect is the growing role of tissue-based rather than strictly time-based treatment selection. Several large clinical trials, including DAWN, DEFUSE 3, and EXTEND, demonstrated that selected patients may benefit from reperfusion therapy even beyond the traditional therapeutic window when significant salvageable tissue is present [18]. Our observations are in agreement with these data and further support the value of CT perfusion in individualized stroke management.

The present study has several limitations. It is retrospective and includes a relatively small number of representative clinical cases from a single center. In addition, interpretation of perfusion studies may vary depending on acquisition protocols, software algorithms, and operator experience [19]. Nevertheless, the presented cases reflect routine clinical practice and demonstrate the practical applicability of CT perfusion in everyday stroke imaging.

Overall, CT perfusion imaging provides clinically relevant information that cannot be obtained from conventional CT alone. Its use improves evaluation of brain tissue viability, facilitates patient selection for reperfusion therapy, and contributes to more individualized treatment strategies in acute ischemic stroke.

The present report is limited by the small number of cases and the retrospective design. Larger prospective studies are required to further validate the predictive value of CT perfusion parameters in treatment selection and outcome prediction.

Conclusion

In the presented patients, CT perfusion provided important additional information that was not fully evident on conventional non-contrast CT. The ability to distinguish between ischemic penumbra and infarct core was helpful when evaluating eligibility for thrombolytic therapy and estimating the risk of unfavorable evolution. In our experience, CT perfusion was particularly useful in patients with subtle early ischemic changes and contributed to more confident therapeutic decision-making in the acute stage of stroke.

Ethics Statement

All imaging data were retrospectively reviewed and anonymized. No identifiable patient information was included in the study.

Author Contributions

S.E.S. contributed to study conception, imaging analysis, data collection, manuscript preparation and final approval of the manuscript.

Conflict of Interest

The author declared no conflict of interest.

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