Clinicoradiological application of the use of spectral cranial computed tomography in the management of acute ischemic stroke after mechanical thrombectomy

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Introduction. Acute ischemic stroke is one of the leading global causes of morbidity and mortality. Mechanical thrombectomy has improved the functional prognosis of this condition; however, hemorrhagic transformation is a common complication. Spectral computed tomography (CT) imaging, as a neuroimaging control test, distinguishes contrast extravasation from hemorrhagic transformation due to the differential behavior of materials at dual energy levels. This distinction is valuable in its clinical therapeutic management.

Material and methods. A single-center, observational, retrospective study was conducted in which the presence of various clinical, radiological, and therapeutic variables in patients with acute ischemic stroke treated with mechanical thrombectomy at our hospital between July 2022 and March 2023 was investigated using access to a dissociated database and medical records.

Results. Out of 155 included patients, spectral cranial CT was performed in 63, and conventional cranial CT in 75. In the spectral CT group, 21 hyperdense images were detected, compared to 28 in the conventional CT group. In 42.8% of cases where hyperdensity was detected in the conventional CT group, it was not possible to distinguish between contrast extravasation and hemorrhagic transformation, in contrast to the 4.8% in the spectral CT group ($p < 0.001$).

Conclusion. Spectral CT provides high diagnostic confidence to the radiologist in identifying the type of detected hyperdensity, thereby offering significant therapeutic confidence to the neurologist in early resuming anticoagulation therapy.

Key words. Atrial fibrillation. Extravasation of diagnostic and therapeutic materials. Ischemic stroke. Radiography dual-energy scanned projection. Thrombectomy. Tomography X-ray computed.

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Accepted:
12.04.24.

Conflict of interests:
There are no relationships related to this work that could be considered as potential conflicts of interest.

How to cite this article:
Moreno-Navarro L, Farrerons-Llopart M, López-Hernández N, Moliner-Castellano S, Ballesteros-Aparicio MJ, Gallego-León J, et al. Clinicoradiological application of the use of spectral cranial computed tomography in the management of acute ischemic stroke after mechanical thrombectomy. Rev Neurol 2024; 78: 247-52. doi: 10.33588/rn.7809.2023340.

Versión española disponible en www.neurologia.com

Introduction

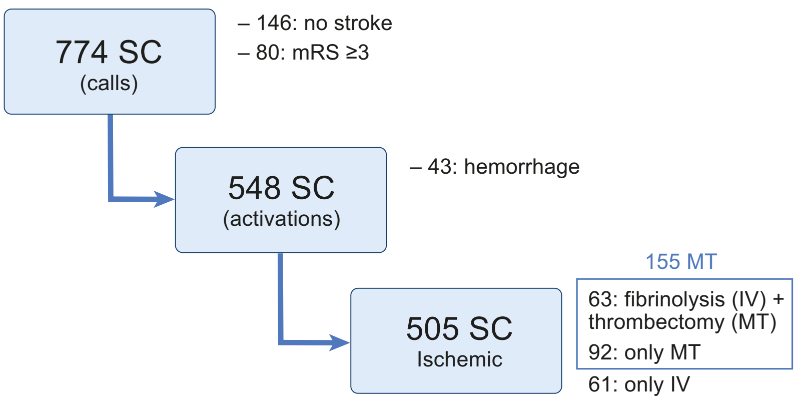
Acute ischemic stroke is one of the leading causes of morbidity and mortality worldwide [1]. Mechanical thrombectomy has become a highly effective and widely used therapeutic procedure for this condition [2]. However, hemorrhagic transformation is one of its most common complications (15%). Hemorrhagic transformation may be periprocedural or occur within 72 hours, and is associated with a poorer functional and vital prognosis [3,4].

The various international guidelines on management of acute stroke recommend that a follow-up neuroimaging test should be performed 24 hours after the procedure in all acute ischemic strokes undergoing revascularization therapy. This is in order to begin antithrombotic treatment quickly if the presence of complications such as hemorrhagic transformation is ruled out [5].

The most frequently performed control neuroimaging test to date has been conventional brain computed tomography (CT). However, this has some disadvantages, as the radiologist cannot distinguish between contrast extravasation and hemorrhagic transformation, as iodine and blood have the same radiological density, with the clinical implications that this entails. However, these difficulties should be overcome with the development of spectral CT, thanks to the different behaviors of the two materials with respect to dual energy [6].

In this context, a longer duration or more passes during mechanical thrombectomy may not only reflect the complexity of the case, but may also provide a surrogate marker of the amount of intravenous contrast used. It is therefore to be anticipated that the higher the level of technical complexity, the greater the probability of complications such as hemorrhagic transformation, and the more con-

Figure 1. Diagram of patients included in the study. During the nine-month study period, 155 mechanical thrombectomies (alone or combined with fibrinolysis) were performed in a total of 505 patients diagnosed with acute ischemic stroke after activation of the Stroke Code. IV: intravenous fibrinolysis; mRS: modified Rankin scale (a score of 3 points or more indicates an unfavorable baseline situation that contraindicates the possibility of revascularization therapy); MT: mechanical thrombectomy; SC: stroke code.



trast used, the greater the probability of contrast extravasation, and it is in these situations that spectral CT could have a better diagnostic performance.

The objective of this study is therefore to set out the different levels of diagnostic confidence for the radiologist, depending on whether conventional or spectral brain CT is used to distinguish between contrast extravasation and hemorrhagic transformation in the population with acute ischemic stroke undergoing mechanical thrombectomy at our hospital, as well as the potential clinical applications arising from it.

Material and methods

This is a single-center, analytical, observational, longitudinal and retrospective study, in which the presence of a series of clinical, radiological and therapeutic variables in all the patients diagnosed with acute ischemic stroke who were treated with mechanical thrombectomy in our hospital was investigated by accessing a database dissociated from our stroke unit and the electronic medical records. The study period was from July 1st 2022 (the date on which spectral CT began to be used within a portfolio of services at the hospital) to March 31st 2023. The number of patients included in the study was 155 (Fig. 1).

The following variables were collected: the type of brain CT used as a control image at 24 hours, i.e. conventional or spectral (whether the patients received a conventional or spectral brain CT was a random factor, and depended on the availability of the CT room when the test took place), the presence or absence of a hyperdense lesion in the brain CT, and the definition of hyperdensity according to the radiological report (hemorrhagic transformation, contrast extravasation, subarachnoid hemorrhage or no distinction of the type of hyperdensity).

The secondary variables collected were the mechanical thrombectomy technique used (aspiration, stent retriever, and intracranial and/or carotid stent in the acute phase), the number of passes performed, the time between arterial puncture and recanalization, the time between onset of symptoms and recanalization, and the degree of recanalization according to the modified Treatment in Cerebral Infarction score.

The SPSS 27.0 software package (Chicago, United States) was used for the statistical analysis. Frequency and association measures were used according to the type of variable and their distribution. The quantitative variables were presented descriptively as the mean ($\bar{x}$) ± standard deviation (or the median and interquartile range, depending on the degree of symmetry). These variables were analyzed using the non-parametric Mann-Whitney U test. The qualitative variables were presented as a number *(n)* and a percentage (%), and were analyzed using the chi-square test and Fisher's exact test. Statistical significance was set at $p < 0.05$.

This study was approved by the research ethics committee of our hospital's health department (PI2023-082), as it complied with the established ethical standards.

Results

Seventeen of the 155 patients included in the study (totaling 79 women and 76 men) did not undergo a 24-hour control brain CT, 63 underwent brain CT with spectral technology, and 75 underwent brain CT with conventional technology (Fig. 2). The mean age of the sample was 72.50 ± 11.60 years.

The clinical, radiological and therapeutic characteristics of the patients with 24-hour control conventional and spectral brain CT are presented in the table.

Approximately half of the patients had high blood pressure and/or dyslipidemia as cerebrovascular risk factors. Likewise, nearly 40% presented atrial fibrillation.

For the mechanical thrombectomy, a mixed technique (aspiration + stent retriever) was used for

Figure 2. Type of brain CT scan used as a control image 24 hours after MT. Of the 155 patients who underwent MT, 63 underwent spectral brain CT, while 75 underwent conventional brain CT. Twenty-one hyperdense images were detected in the spectral group, while there were 28 hyperdense images in the conventional group. CT: computed tomography; MT: mechanical thrombectomy; *n*: number.

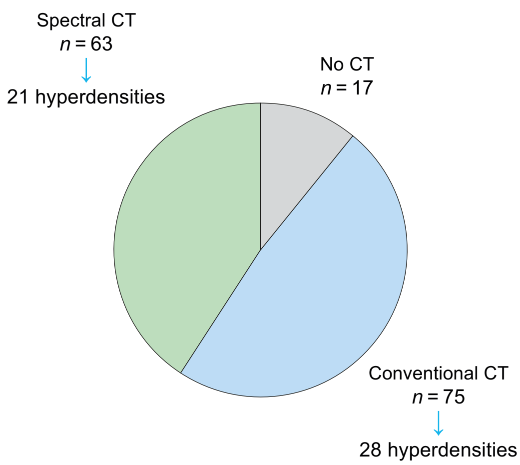
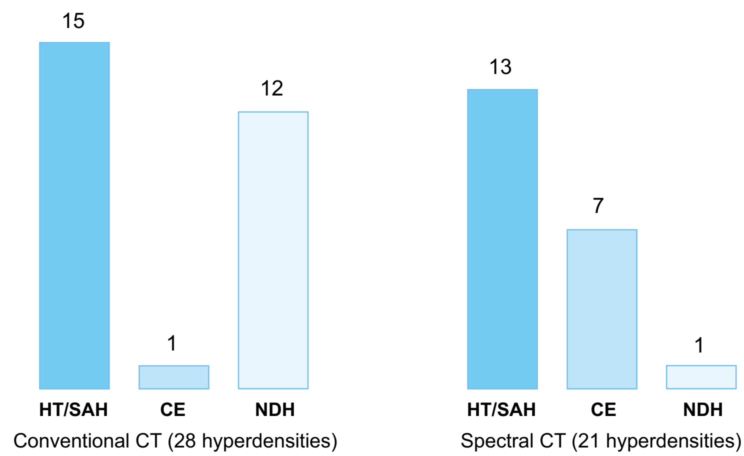


Figure 3. Definition of the hyperdensity detected according to the radiological report and type of CT scan. Classification of hyperdense images detected in each type of CT scan according to the image analysis performed by the radiologist on duty. No distinction between blood and contrast was possible in 42.8% of the control image cases with conventional CT (NDH = 12/28), unlike spectral CT (NDH = 1/21); $p < 0.001$. CE: contrast extravasation; CT: computed tomography; HT: hemorrhagic transformation; NDH: no distinction of the type of hyperdensity; SAH: subarachnoid hemorrhage.



53.6%; only aspiration for 41.3%; and only a stent retriever for 5.1%. In addition, in the acute phase an intracranial stent was used in 2.9%, and a carotid stent in 12.3%. The median number of passes was 2 (interquartile range: 1-3). The median time between arterial puncture and recanalization in conventional CT was 48 (interquartile range: 25-82), and in spectral CT, it was 41 (interquartile range: 20- 67). Successful reperfusion (modified Treatment In Cerebral Infarction score ≥ 2b) was achieved in 126 patients (91.3%).

In the control brain CT 24 hours performed after thrombectomy, 21 hyperdense images were observed in the spectral CT group, while 28 were detected in the conventional CT group. The categorization of these hyperdensities according to the radiological report is summarized in figure 3. No distinction in the type of hyperdensity was observed in 42.8% of the cases of hyperdense image in conventional CT, while in spectral CT it was in 4.8%, which were statistically significant differences ($p < 0.001$).

Discussion

In 95.2% of the cases in which spectral CT was used as a control test, the radiologist was able to establish a diagnosis of hemorrhagic transformation, subarachnoid hemorrhage or contrast extravasation after detecting a hyperdense image thanks to the image post-processing program linked to this technology. This suggests that under optimal conditions, the diagnostic confidence of spectral CT would be close to 100% in patients with acute ischemic stroke treated with mechanical thrombectomy, as shown in recently published series of cases [6-8].

This major diagnostic improvement of spectral CT compared to conventional CT (4.8% versus 42.8% of non-distinction of the type of hyperdensity in our series), together with the fact that the spectral image analysis process takes only two minutes per patient [6], means it can be integrated into routine clinical-radiological practice.

For patients with acute ischemic stroke undergoing mechanical thrombectomy (and especially those with atrial fibrillation as an etiologic comorbidity, which was 40% of our series), one of the potential clinical applications would be earlier clinical management in the reintroduction of their anticoagulant therapy.

Two recent studies [9,10] have shown promising results regarding the prognostic advantages of an earlier resumption of anticoagulant therapy in these patients, provided that the presence of hemorrhaging as a post-procedural complication can be entirely ruled out in the control image. Both studies observed a reduction in the recurrence of embolism (both systemic and stroke) to around half, with

Table. Clinical, radiological and therapeutic features. Includes subanalysis of 'NDH' versus 'CE + HT/SAH' cases from the conventional CT group.

Variables to be studied/type of 24-hour control brain CT scan	Conventional CT (*n* = 75)	Spectral CT (*n* = 63)	*p*-value	NDH (conventional CT) (*n* = 12)	CE + HT/SAH (conventional CT) (*n* = 16)	*p*-value
Age, years, x̄ ± SD	73.95 ± 10.41	71.17 ± 13.46	0.383	76.92 ± 9.38	74.06 ± 7.75	0.401
Women, *n* (%)	36 (48)	33 (52.4)	0.608	7 (58.3)	7 (43.8)	0.445
Comorbidities						
Smoking, *n* (%)	15 (20)	14 (22.2)	0.92	2 (16.6)	6 (37.5)	0.118
High blood pressure, *n* (%)	38 (50.7)	35 (55.6)	0.58	5 (41.7)	12 (75)	0.15
Diabetes mellitus, *n* (%)	13 (17.3)	13 (20.6)	0.391	2 (16.7)	5 (31.3)	0.376
Dyslipidemia, *n* (%)	38 (50.7)	30 (47.6)	0.832	7 (58.3)	7 (43.8)	0.301
Atrial fibrillation, *n* (%)	28 (37.3)	27 (42.9)	0.472	8 (66.7)	7 (43.8)	0.229
Known	18 (24)	21 (33.4)	0.5	7 (58.3)	5 (31.3)	0.168
De novo	10 (13.3)	6 (9.5)	0.441	1 (8.33)	2 (12.5)	0.611
Baseline NIHSS, Me (IQR)	17 (11-22)	17 (10-21)	0.508	14.5 (8.25-23.75)	17.5 (14.25-20)	0.388
Initial multimodal study						
NCCT-ASPECTS. x̄ ± SD	8.47 ± 1.5	8.22 ± 1.57	0.41	8.92 ± 1.51	8.50 ± 1.46	0.423
CTASI-ASPECTS. x̄ ± SD	8.1 ± 1.89	8 ± 1.8	0.729	8.8 ± 1.64	7.50 ± 2.38	0.286
Tan Collateral Score 2/3, *n* (%)	60 (80)	48 (76.2)	0.661	6 (50)	9 (56.25)	0.652
Occlusion location, *n* (%)						
Intracranial ICA	11 (14.7)	9 (14.3)		1 (8.33)	5 (31.3)	
MCA-M1	36 (48)	30 (47.6)		6 (50)	8 (50)	
MCA-M2	13 (17.3)	10 (15.9)	0.927	1 (8.33)	2 (12.5)	0.307
Tandem (ICA + MCA)	10 (13.3)	11 (17.4)		3 (25)	1 (6.33)	
Basilar artery	5 (6.7)	3 (4.8)		1 (8.33)	0 (0)	
Intravenous fibrinolysis, *n* (%)	37 (49.3)	24 (38.1)	0.246	4 (33.3)	9 (56.2)	0.125
Mechanical thrombectomy						
Aspiration, *n* (%) (total)	71 (94.7)	60 (95.2)		12 (100)	16 (100)	
ACE 68	4 (5.3)	2 (3.2)		0 (0)	2 (12.5)	
CATALYST 6	24 (32)	16 (25.4)		5 (41.7)	5 (31.3)	
JET 7	4 (5.3)	5 (7.9)	0.461	1 (8.3)	0 (0)	0.275
REACT 68/71	8 (10.7)	9 (14.3)		2 (16.7)	1 (6.3)	
RED 62/68/72	29 (38.7)	28 (44.4)		4 (33.3)	8 (50)	
Stent retriever, *n* (%) (total)	42 (56.0)	39 (61.9)		8 (66.7)	11 (68.8)	
CatchView	9 (12)	7 (11.1)		1 (8.3)	1 (6.3)	
NeVa	6 (8)	4 (6.3)		1 (8.3)	2 (12.6)	
Solitaire	16 (21.3)	18 (28.6)	0.284	4 (33.3)	5 (31.3)	0.579
Tigertriever	0 (0)	1 (1.6)		0 (0)	0 (0)	
Trevo	11 (14.7)	9 (14.3)		2 (16.7)	3 (18.8)	
Proportion with mixed technique, *n* (%)	38 (50.7)	36 (57.1)	0.696	8 (66.7)	11 (68.8)	0.907
Intracranial stent in acute phase, *n* (%)	3 (4.0)	1 (1.6)	0.75	0 (0)	1 (6.3)	0.571
Atlas stent	1 (1.3)	0 (0)		0 (0)	0 (0)	
Credo stent	2 (2.7)	1 (1.6)		0 (0)	1 (6.3)	
Carotid stent in acute phase, *n* (%)	10 (13.3)	7 (11.1)	0.588	2 (16.7)	2 (12.5)	0.755
Carotid Wallstent	9 (12)	7 (11.1)		2 (16.7)	2 (12.5)	
Roadsaver Stent	1 (1.3)	0 (0)		0 (0)	0 (0)	
Number of passes, Me (IQR)	2 (1-3)	2 (1-3)	0.878	3 (1-5)	2 (1-3)	0.302
GTR, minutes, Me (IQR)	48 (25-82)	41 (20-67)	0.192	72.5 (42-133.75)	69.5 (34-108.75)	0.631
OTR, minutes, Me (IQR)	406 (252-814)	346 (248-748)	0.416	412 (306-626)	439.5 (363.5-989)	0.324
mTICI 2b/2c/3, *n* (%)	66 (88)	60 (95.2)	0.722	11 (91.7)	15 (93.8)	0.683
Control brain CT scan after 24 hours						
Hyperdense image, *n* (%)	28 (37.3)	21 (33.3)				
CE	1 (3.6)	7 (33.3)				
NDH	12 (42.8)	1 (4.8)	<0.001			
HT/SAH	15 (53.6)	13 (61.9)				

ASPECTS: Alberta Stroke Program Early Computerized Tomography Score; CTASI: computed tomography angiography source images; CE: contrast extravasation; CT: computed tomography; GTR: groin puncture-to-recanalization time; HT: hemorrhagic transformation; ICA: internal carotid artery; IQR: interquartile range; MCA: middle cerebral artery; Me: median; mTICI: modified Treatment In Cerebral Infarction; *n*: number; NCCT: non-contrast computed tomography; NDH: no distinction of the type of hyperdensity; NIHSS: National Institute of Health Stroke Scale; OTR: onset-to-recanalization time; SAH: subarachnoid hemorrhage; SD: standard deviation. x̄: mean; %: percentage.

no increase in the incidence of intra- or extracranial hemorrhage compared to the group received conventional treatment (late resumption of anticoagulant therapy), with the consequent long-term prognostic improvement of these patients.

This study has several limitations. First, it took place at a single hospital, and as such our results may not be generalizable. Moreover, as it is a retrospective study, no significant number of brain MRI scans had been performed to enable us to correlate the findings obtained in the control brain CT scan. Second, there may have been a rate of data loss in the number of control brain CT scans performed in patients belonging to other health departments who were referred to their referral hospital before the 24-hour period after the endovascular procedure had elapsed (since our hospital is the only center in the province that has an on-call team for interventional neuroradiology).

Conclusions

The distinction between hemorrhagic transformation, subarachnoid hemorrhage and contrast extravasation is important for the functional and vital prognosis of patients with acute ischemic stroke treated with mechanical thrombectomy. The use of spectral technology in the 24-hour control brain CT scan, which is performed systematically in these patients, gives the radiologist increased diagnostic confidence when establishing the type of hyperdensity detected and therefore gives the neurologist enhanced therapeutic confidence to resume anticoagulation therapy at an earlier stage in cases of stroke and atrial fibrillation.

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Aplicación clinicorradiológica del uso de la tomografía computarizada craneal de tecnología espectral en el manejo del ictus isquémico agudo tras trombectomía mecánica

Introducción. El ictus isquémico agudo es una de las principales causas globales de morbimortalidad. La trombectomía mecánica ha mejorado el pronóstico funcional de esta patología; sin embargo, la transformación hemorrágica es una complicación frecuente. La tomografía computarizada (TC) de tecnología espectral, como prueba de neuroimagen de control, diferencia la extravasación de contraste de la transformación hemorrágica gracias al diferente comportamiento de los materiales a la energía dual, y esta distinción es de utilidad en su manejo clinicoterapéutico.

Material y métodos. Estudio unicéntrico, observacional y retrospectivo, en el cual se investigó, mediante el acceso a una base de datos disociada y a la historia clínica, la presencia de una serie de variables clínicas, radiológicas y terapéuticas en los pacientes con ictus isquémico agudo que fueron tratados con trombectomía mecánica en nuestro hospital entre julio de 2022 y marzo de 2023.

Resultados. De los 155 pacientes incluidos, se realizó una TC craneal espectral en 63 y convencional en 75. En el grupo de TC espectral se detectaron 21 imágenes hiperdensas y en el grupo de TC convencional fueron 28. En el 42,8% de los casos en los que se detectó una hiperdensidad en el grupo de TC convencional no se pudo distinguir entre extravasación de contraste y transformación hemorrágica, en comparación con el 4,8% del grupo de TC espectral (p < 0,001).

Conclusiones. La TC espectral confiere una gran confianza diagnóstica al radiólogo para establecer el tipo de hiperdensidad detectada y, por ello, proporciona también una gran confianza terapéutica al neurólogo para reiniciar precozmente la anticoagulación.

Palabras clave. Accidente cerebrovascular isquémico. Extravasación de materiales terapéuticos y diagnósticos. Fibrilación auricular. Imagen radiográfica por emisión de doble fotón. Tomografía computarizada por rayos X. Trombectomía.