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ORIGINAL ARTICLE

Clinical prediction scale approach derived from a retrospective study to reduce the number of urgent, low-value cranial CT scans

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Abstract

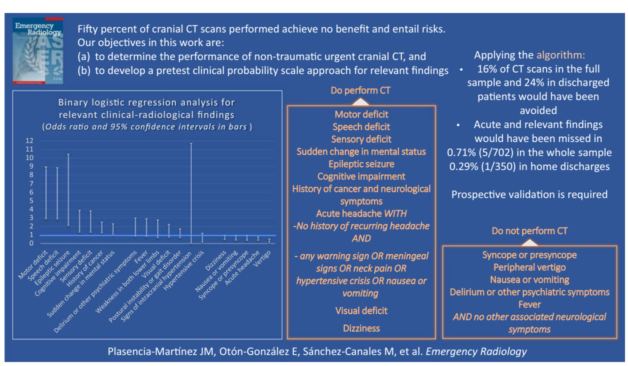
Purpose Fifty percent of cranial CT scans performed achieve no benefit and entail risks. Our aim is to determine the yield of non-traumatic urgent cranial-CT and develop a pretest clinical probability scale approach.

Methods Adult patients seen in our emergency department between 2017–2021 and referred for urgent cranial-CT for non-traumatic reasons were retrospectively recruited and randomly selected. Presenting complaint (PC), demographic variables, Relevant radiological findings (RRF) on the urgent cranial-CT and Relevant clinical-radiological findings (RCRF: admission need or RRF detection on the urgent cranial-CT or cranial CT/MRI in the following three months) were recruited.

Results We recruited 702 patients, with median age 62 [47–76] years, 363 (51.7%) females. RCRF were observed in 404 (57.55%); of these, 352 (50.1%) required admission. RRF were detected in 190 (27.06%): 36 acute ischemic and 27 acute hemorrhagic lesions, 115 masses, 9 edema, and 27 hydrocephalus. Predictive PC for urgent cranial-CT were motor, speech, sensory deficits, sudden alteration of mental status, epileptic seizure, cognitive impairment, neurological symptoms in cancer patients, acute headache without a prior history and with meningeal signs; nausea, vomiting, or hypertensive crisis; visual deficits, and dizziness. This algorithm provided sensitivity, specificity, positive predictive value, and negative predictive value (NPV, 95%CI in brackets) of 92.1% (89–94.5%), 27.5% (22.5–33.0%), 63.3% (59.2–67.2%), and 71.9% (62.7–80.0%), to diagnose RCRF, and 97.4% (93.4–99.1%), 21.3% (17.8–25.1%), 31.5% (27.7–35.4%), and 95.6% (90.1–98.6%), to diagnose RRF. In patients not requiring admission (n = 350), the NPV for RRF was 98.8% (93.6–100%); the negative likelihood ratio 0.08 (0.01–0.57), and sensitivity remained at 97.8% (82.2–99.9%). Applying it would have avoided performing 85/350 urgent cranial-CT (24.29%). To find one RRF, we would have gone from performing 7.8 (350/45) to 5.9 (265/45) CTs, failing to diagnose 1/45 (2.2%) RRF.

Conclusions This proposed clinical scale could potentially decrease 24% of urgent cranial-CT.

Graphical Abstract



Keywords Multidetector Computed Tomography · Neurology · Diagnosis · Guidelines · Emergency department

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Introduction

Low-value medical care includes services that yield little or no benefit to patients, are potentially dangerous, and represent an unnecessary expense [1]. In radiology, these are imaging tests with lower diagnostic value because they lack relevant findings, or because their impact on the clinical decision is negligible at best [1], while increasing the expense and doses of unnecessary radiation and contrast agents [2, 3]. Such is the case in 20–50% of radiological examinations, surpassing 50% of cranial CT [1] (Supplementary file 1). Relevant findings in cranial CT appeared in < 11% of consultations for headache (2–8%), delirium (3–11%), syncope (4%) [4], hepatic encephalopathy (4%), or the need for admission to medical services (4%) [5]. While we hypothesize that predicting the diagnosis performance of cranial CT based on neurological presenting complaints (PC) may decrease unnecessary testing, the impact of that information and other recommendations, such as those of the *National Institute for Health and Care Excellence's* (NICE's) *"Do-not-do list*," *iRefer*, *iGuide,* and *The international Choosing Wisely* has been scant [1], and it is likely that the solutions can derive from local spheres. Our main objective is to determine the diagnosis performance of Urgent non-traumatic cranial CT in adults without a history of trauma in our setting. The secondary objective is to develop an algorithm that can serve as a pretest scale for diagnostic prediction.

Material and methods

Design

This cross-sectional retrospective study was approved by the Research Committee (registration number CETI 02/22) and complies with the STARDS guidelines [6] (Supplementary file 2). Patients' informed consent was not required. Patients were not involved in the design and conduct of this research.

Participants

The sample was randomly selected and comprised: 1) patients > 18 years old; 2) cranial CT performed for non-traumatic cause, between January 2017 and January 2022, in the emergency department of our second level hospital, a healthcare area referral; 3) clinical data at the time of CT and follow-up were available in the information systems.

Individuals were excluded if they presented the following: 1) history of cranial trauma in the month prior to the urgent CT; 2) known cerebral neoplasms; 3); clinically monitored brain abscess or recent cerebritis; 4) hydrocephalus with ventricular shunt, and 4) intracranial hemorrhage or ischemia radiologically diagnosed in the previous three months.

Test methods

Variables for setting up the algorithm

Clinical variables In addition to age, sex, and personal history, we analyzed the PC detailed in Supplementary file 3. They were collected in a standardized manner in the emergency department discharge report and classified dichotomously as present/absent.

Radiological variables The diagnoses of acute ischemia, acute hemorrhage, intra/extracerebral mass, edema, and unknown hydrocephalus were deemed relevant acute radiological findings (RRF). These variables were collected in the radiological reports issued by emergency department radiologists, on-call radiologists, or residents in radiology with at least three months of neuroradiology training. Most of the CT with reports issued between 3:00 pm and 8:00 am were reviewed the next day by a neuroradiologist with more than 30 years' experience who added the RRF that may not have been detected to the report.

Follow-up variables To establish the severity and nature of the clinical symptoms and possible undetected lesions on the CT of the first consultation (hereinafter "first CT"), we recorded: 1) type of medical care provided following the first consult, dichotomized as hospital admission or home discharge, and 2) if the patient underwent a new cranial CT or cranial MRI during the three months following the first consult, whether in the emergency department, outpatient services, or hospitalization. In this case, note was taken if there were undetected RRF on the first CT. When the subject underwent CT for a new consultation in the emergency department after three months of the first CT, it was considered a new case.

Reference standard The main objective was to safely lower the number of CT scans without RRF. However, given that no test is free of false negatives and in the presence of neurological conditions for which CT may not be diagnostic or may be so later, we regarded limiting our outcome variable to RRF as insufficient. To minimize false negatives and achieve the maximum sensitivity of the algorithm, we considered Urgent non-traumatic cranial CT to be indicated for all patients who required hospital admission, and in whom a new finding was detected on follow-up testing (CT or MRI) in the three months following the first CT. Thus, our main outcome variable was a combined variable called Relevant Clinical or Radiological Findings (RCRF) that was deemed positive when at least one of the following three conditions was met: 1) a RRF on the first consult CT; 2) hospitalization, and 3) a RRF on cranial CT or MRI performed in the three months following a normal first CT. The RRF variable was the second outcome variable.

Operators Five operators, three second year and two third-year radiology residents collected the data with no blinding as to clinical, follow-up, or radiological variables. Clinical and follow-up variables were extracted from the clinical history and the radiological variables from the radiological reports on the CT or, when appropriate, the MRI. When any clinical variable in the report was unclear, it was considered absent.

Statistical analysis

In order to calculate the sample size, considering a proportion of 20% of positive findings on the cranial CT, the minimum theoretical initial sample of 685 was needed to be able to estimate this proportion with 3% accuracy.

The variables derived from the sample have been represented as absolute and relative frequencies (qualitative variables), and means and standard deviation, or median and interquartile range, according to distribution (quantitative variables).

The statistical differences regarding the RRF based on each clinical variable was analyzed by Chi^2 or t-Student tests.

To establish the diagnosis performance of the Urgent non-traumatic cranial CT with the different PC, binary logistic regression models were performed considering RCRF and RRF as dependent variables and predictive of each PC. We also included sex, age, oncological patient, and operator to avoid ruling out possible confounding factors. We considered that a PC was associated with a RCRF or RRF when its Odds Ratio (OR) was significant according to the Wald test [7]; and that performing the cranial CT would be useful (diagnostic advantage) if the OR > 1, and not (diagnostic disadvantage) if the OR < 1.

With the statistical PC that were predictive and non-predictive of the usefulness of the cranial CT, a pretest scale model of the probability of RCRF and RRF was created that reported on the usefulness of the test. Its sensitivity, specificity, predictive values (PV), and likelihood coefficients (LC) would be found.

Statistical significance was deemed when $p < 0.05$. The IBM SPSS version 20, MedCalc 12.7.0.0, and Excel 365 were used.

Results

Sample analysis

The sample consisted of 702 subjects; median age of 62 years and interquartile range of 47–76 years; 363 (51.7%) were female, and 202 (28.8%) had a history of cancer (Supplementary file 4–5).

Five hundred and seventy-two (81.5%) CT scan without intravenous contrast were performed and 130 (18.5%) with intravenous contrast, who may or may not have undergone CT scanning without intravenous contrast.

Four hundred and four (57.55%) had RCRF; of them, 352 (50.1%) required hospitalization, and 190 (27.06%) had some kind of RRF. To detect a RRF, 3.7 CT were conducted in the whole sample (702/190) and 7.8 CT in individuals not requiring admission (350/45). The RRF were a) 36 (5.1%) acute ischemias; b) 27 (3.8%) acute hemorrhages (10 intra-axial, 8 subarachnoid, 5 subdural, and 4 several); c) 115 (16.4%) brain masses, 52 with cerebral edema and 10 with hydrocephalus; d) 9 (1.3%) edema cerebral with no mass, and e) 27 (3.8%) unknown hydrocephalus with no associated mass. The reason for admission was neurological in 240/352 (68.18%) and non-neurological in 113/352 (32.10%).

One patient with an acute ischemic cerebellar lesion with hydrocephalus was diagnosed later by a CT scan two days after the first CT.

The most common PC were headache (193, 27%), sudden change in mental status (164, 23.4%), speech deficit (110, 15.7%), motor deficit (107; 15.2%), and postural instability or gait disturbance (100, 14.2%). A total of 256 subjects (36.5%) consulted for a single PC, 443 (63.10%) for more than one, and 3 (0.4%) for none.

RCRF predictive capacity of PC

Considering RCRF and RRF as dependent variables and PC as independent variables, we performed a Chi^2 analysis (Supplementary file 6) and a binary logistic regression analysis for each PC.

1. We initially analyzed the whole sample (Table 1; Fig. 1). Based on the statistical significance of the OR for each PC, the following groups were established:

Group 1 (predictive PC) Variables that increased the risk of RCRF (OR > 1; $p < 0.05$, Fig. 1a) were: motor deficit, speech deficit, seizure, cognitive impairment, sensory deficit, oncological history and sudden disturbance of mental status. Motor deficit, speech deficit, epileptic

Table 1 Results of the predictive ability of relevant clinical and/or radiological findings of the different presenting complaint using the binary logistic regression test

Presenting complaint	Relevant clinical-radiological findings					Relevant radiological findings				
	OR[a]	CI95%		P	R2	OR[a]	CI95%		P	R2
Motor deficit	5.09	2.89	8.94	**<.001**	0.13	2.42	1.68	3.48	**<.001**	0.10
Speech deficit	5.04	2.87	8.85	**<.001**	0.13	2.85	1.84	4.42	**<.001**	0.10
Epileptic seizure	4.69	2.11	10.44	**<.001**	0.09	2.89	1.54	5.43	**0.001**	0.08
Cognitive impairment	2.64	1.32	3.85	**0.003**	0.08	1.72	0.98	3.02	0.06	0.07
Sensory deficit	2.25	1.30	3.80	**0.003**	0.08	1.20	0.69	2.07	0.524	0.06
History of cancer	1.75	1.24	2.48	**0.002**	0.06	2.28	1.60	3.26	**<.001**	0.06
Sudden change in mental status	1.55	1.06	2.29	**0.026**	0.07	1.25	0.84	1.86	0.282	0.06
Delirium or other psychiatric symptoms	1.58	0.84	2.97	0.161	0.06	0.88	0.45	1.74	0.71	0.06
Fever	1.51	0.80	2.88	0.207	0.06	0.78	0.39	1.60	0.502	0.06
Weakness in both lower limbs	1.36	0.68	2.73	0.386	0.06	0.81	0.38	1.76	0.598	.063
Visual deficit	1.26	0.72	2.22	0.416	0.06	1.18	0.63	2.23	0.604	0.06
Postural instability or gait disorder	1.07	0.68	1.68	0.76	0.06	1.56	0.98	2.46	0.061	0.07
Signs of intracranial hypertension	0.72	0.04	11.70	0.818	0.06	-	-	-	-	-
Hypertensive crisis	0.42	0.15	1.17	0.098	0.06	0.89	0.28	2.84	0.849	0.06
Dizziness	0.65	0.45	0.94	**0.023**	0.07	0.89	0.58	1.36	0.591	0.06
Nausea or vomiting	0.59	0.39	0.92	**0.019**	0.06	0.72	0.43	1.20	0.21	0.07
Syncope or presyncope	0.58	0.36	0.94	**0.027**	0.07	0.54	0.30	0.99	0.05	0.07
Acute headache	0.53	0.37	0.76	**0.001**	0.08	0.93	0.61	1.41	0.73	0.06
Vertigo	0.27	0.14	0.51	**<.001**	0.09	0.36	0.16	0.84	**0.02**	0.08

[a:] Each row represents a binary logistic regression model that includes the presenting complaint as a predictor of outcome findings (yes vs. no) adjusted for sex, age, cancer patient and operator. The odds ratio (OR) indicates a higher chance of finding relevant CT findings when presenting the presenting complaint over not presenting it

Nagelkerke R2 on the goodness-of-fit of the model for each predictor variable "presenting complaint"

Statistically significant ORs (*P* value < 0.05) are in bold. Predictor variables with no relevant CT findings cases are not shown

seizure, and prior history of oncological disease were also PC predictive of RRF (Fig. 1b). In 383 cases (54.56%), one or more predictive PC were present.

Group 2 Variables bearing no influence on RCRF or RRF in the whole sample (OR includes the value 1; $p > 0.05$; Figs. 1a and b) were: visual deficit; postural instability or gait disturbance; delirium-psychiatric symptoms; fever; hypertensive crisis; weakness in both legs, and signs of intracranial hypertension.

Group 3 (protective PC) Variables that decreased the risk of RCRF (OR < 1; $p < 0.05$; Fig. 1a) were: dizziness, nausea-vomiting (OR 0.594; 95%CI 0.385–0.917; $p = 0.019$); syncope-presyncope (OR 0.580; 95%CI 0.357–0.941; $p = 0.027$); acute headache (OR 0.528; 95%CI 0.368–0.756; $p = 0.001$), and vertigo (OR 0.267; 95%CI 0.142–0.505; $p < 0.001$). The PC syncope-presyncope and vertigo also resulted in a reduced likelihood of RRF (Fig. 1b). There were 169 subjects (24.07%) with one or more protective PC, with no predictive PC.

2. Second, to keep biases from canceling the predictive capacity of the PC acute headache, particularly for the RRF of acute hemorrhage, the variable *Combined Acute Headache* was created: acute headache with no history of headache and at least one other PC among stiff neck or other meningeal sign, neck pain, hypertensive crisis, or nausea-vomiting. On the binary logistic regression adjusted for age, sex, and operator, *Combined Acute Headache* failed to predict RCRF (OR 1.268; 95%CI 0.561–2.869; $p = 0.568$), but succeeded in predicting RRF (OR 2.966; 95%CI 1.097–8.017; $p = 0.032$), specifically acute hemorrhage (OR 37.345; 95%CI 5.912–235.912; $p < 0.001$).
3. Finally, to avoid ruling out PC with discriminatory capacity that could have been hidden by the strength of association of the PC in Group 1, the binary logistic regression was repeated, excluding patients who presented for any one of them. Considering only the PC in Groups 2 and 3 as independent variables, adjusted for age, sex, and operator, visual deficit increased the risk

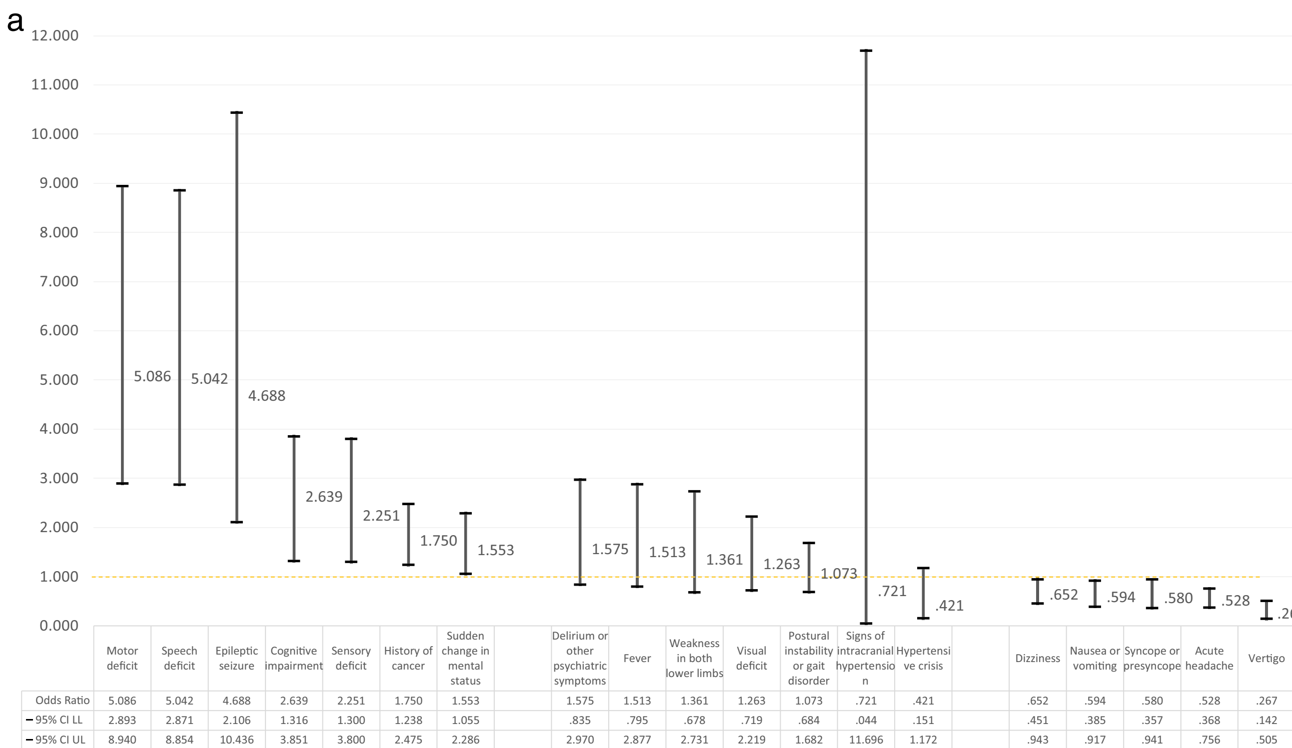


Fig. 1 (**a**) Graphical representation of Table 1 of the binary logistic regression analysis in the full sample for the relevant clinical-radiological findings dependent variable. In the bars, the central value corresponds to the odds ratio and the limits (upper -UL- and lower level -LL-), to their 95% confidence intervals. Value 1 is highlighted on the y-axis to detect those presenting complaints for consultation with odds ratio above 1 (Group 1, predictor presenting complaint, all with *P*-value < 0.05), including value 1 (Group 2) and below 1 (Group 3, protective presenting complaints, all with *P*-value < 0.05). (**b**) Graphical representation of Table 1 of the binary logistic regression analysis in the full sample for the relevant radiological findings dependent variable. In the bars, the central value corresponds to the odds ratio and the limits, to their 95% confidence intervals. Value 1 is highlighted on the y-axis to detect those presenting complaints for consultation with odds ratio above 1 (Group 1, predictor presenting complaint, all with *P*-value < 0.05), including value 1 (Group 2) and below 1 (Group 3, protective presenting complaints, all with *P*-value < 0.05)

of RCRF (OR 2.500; 95%CI 1.201–5.202; $p = 0.014$) and tended to increase that of RRF (OR 2.707; 95%CI 0.993–7.377; $p = 0.052$). Presenting with dizziness increased the risk of RRF (OR 3.979; 95%CI 1.218–12.996; $p = 0.022$).

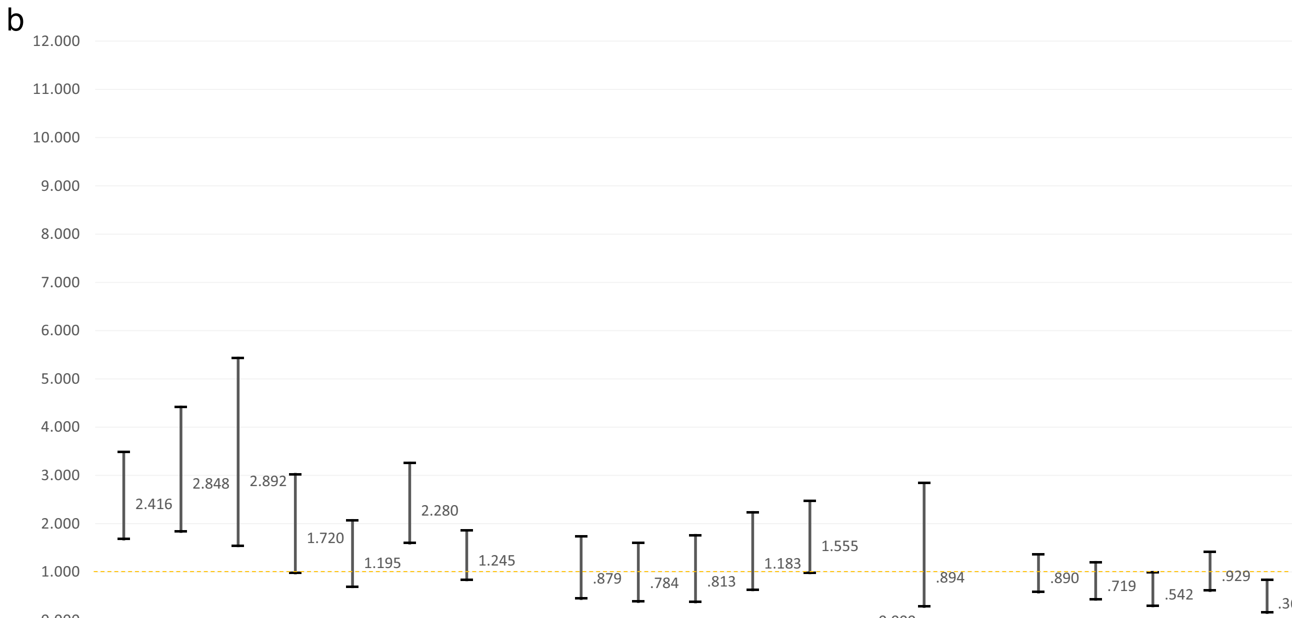
The PC of postural instability or gait disturbance correlated with a higher risk of RRF in the Chi2 analysis of the whole sample (Supplementary file 6), but displayed no predictive ability in the binary logistic regression of the whole sample (Fig. 1b) or in the subgroups described in subsections 2 and 3.

4. The sample size of PC of intracranial hypertension (n = 2), hypertensive crisis (n = 17), and lower limb weakness (n = 39) limited the ability to analyze their predictive capacity.

Algorithm

Considering the aforementioned results, we developed an algorithm to indicate Urgent non-traumatic cranial CT in individuals without trauma (Fig. 2), including as suitable the group 1 PC, history of cancer, combined acute headache, visual deficit, and dizziness. Its sensitivity, specificity, positive PV and negative PV were 92.1% (95%CI 89–94.5%), 27.5% (95%CI 22.5–33.0%), 63.3% (95%CI 59.2–67.2%), and 71.9% (95%CI 62.7–80.0%), to diagnose RCRF, and 97.4% (95%CI 93.4–99.1%), 21.3% (95%CI 17.8–25.1%), 31.5% (95%CI 27.7–35.4%), and 95.6% (95%CI 90.1–98.6%) to diagnose RRF.

In our sample, the algorithm would have reduced the number of CT by 16.2%, with the risk of not diagnosing five cases with RRF (1 acute subarachnoid hemorrhage and 4 masses, one of them with edema and hydrocephalus),



	Motor deficit	Speech deficit	Epileptic seizure	Cognitive impairment	Sensory deficit	History of cancer	Sudden change in mental status		Delirium or other psychiatric symptoms	Fever	Weakness in both lower limbs	Visual deficit	Postural instability or gait disorder	Signs of intracranial hypertension	Hypertensive crisis		Dizziness	Nausea or vomiting	Syncope or presyncope	Acute headache	Vertigo
Odds Ratio	2.416	2.848	2.892	1.720	1.195	2.280	1.245		.879	.784	.813	1.183	1.555	0.000	.894		.890	.719	.542	.929	.363
95% CI LL	1.678	1.836	1.539	.978	.691	1.596	.835		.445	.385	.376	.627	0.981	0.000	.281		.582	.431	.296	.612	.157
95% CI UL	3.479	4.418	5.433	3.023	2.067	3.257	1.856		1.735	1.597	1.758	2.231	2.464		2.839		1.362	1.199	.992	1.410	.836

Fig. 1 (continued)

corresponding to 0.71% (5/702) of the whole sample and 2.6% (5/190) of all RRF. The patient with the undiagnosed cerebellar infarction would have undergone CT if the algorithm were to be applied.

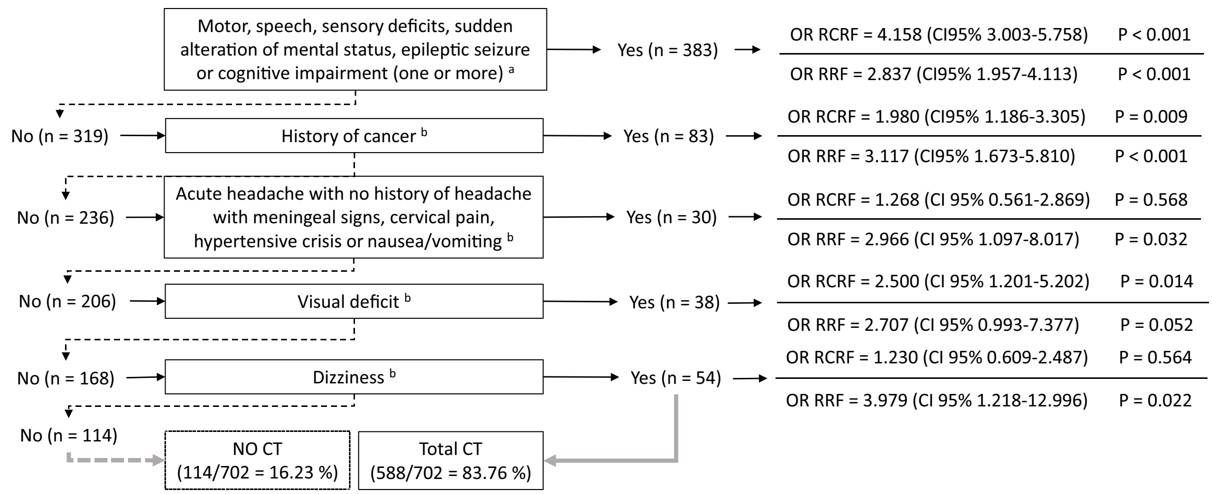
In subjects not requiring hospitalization (n = 350), the algorithm's negative PV for RRF was 98.8% (95%CI 93.6–100%) and the negative LR 0.08 (95%CI 0.01–0.57), with 97.8% sensitivity (95%CI 82.2–99.9%). Among them, 85/350 CT (24.29%) could have been avoided and 1/45 (2.2%) RRF would have not been diagnosed RRF (a mass).

Using the algorithm, we would have gone from 3.7 (702/190) to 3.1 (588/190) CT to find one RRF in the whole sample and from 7.8 (350/45) to 5.9 (265/45) in home discharges.

Discussion

The main benefit of the algorithm proposed is to discourage unnecessary cranial CT in non-traumatic emergencies. It enables acute ischemia, acute hemorrhage, mass, cerebral edema, and hydrocephalus to be detected with sensitivity > 97%, negative PV > 95%, and negative LR < 0.13; lower Urgent non-traumatic cranial CT by 16% in the whole sample and by 24% in home discharges and avoid two CT for each RRF in home discharges. The risk of underdiagnosing any of the previously named conditions was 2.6%, < 1% of the full group of subjects who underwent CT.

Radiological test ordering patterns may be informed not just by risk, but also perception of medicolegal risk, patient preferences, and institutional/practice culture factors. However, the exponential growth in radiological testing without an associated increase in relevant findings [8] carries risks such as iatrogenesis secondary to the ionizing radiation, intravenous contrast medium, incidental findings, and delays in necessary diagnostic tests [9], often downplayed by the prescribing physician and unknown by the patient [8, 10]. It is therefore urgent that these low-value tests be safely decreased. In our study, the present complain that, lacking any other neurological signs or symtoms, lower the probability of RRF are: nausea-vomiting, vertigo, syncope-presyncope, delirium or psychiatric symptoms, and fever. This is consistent with earlier publications and clinical guidelines [11], albeit these guidelines seek to establish indications for CT and not when "not to perform" [11–14]. As for acute headache, several meta-analyses have revealed that radiological testing for a simple headache doubled between the years of 2000 (6.7%) and 2010 (13.9%) [10, 15]. In our sample, headache is the most common PC and one of the ones that decreases the possibility of RRF to almost half when there are no associated threatening signs and symptoms. Previous works indicate that a normal neurological examination in individuals with headache lower the risk of positive findings by 30% [16]. In contrast, CT is



	Sensitivity	Specificity	Positive LR	Negative LR	Positive PV	Negative PV	Undiagnosed cases
Relevant clinical-radiological findings whole sample	92.08% 89.00%-94.52%	27.52% 22.52%-32.96%	1.27 1.18-1.37	0.2 0.20-0.42	63.27% 59.22%-67.17%	71.93% 62.74%-79.94%	32/702 (4.56%[c]); 32/404 (7.92%[d])
Relevant radiological findings whole sample	97.37% 93.97%-99.14%	21.29% 17.82%-25.09%	1.24 1.18-1.30	0.12 0.05-0.30	31.46% 27.73%-35.39%	95.61% 90.06%-98.56%	5/702 (0.71%[c]); 5/190 (2.63%[d])
Relevant clinical-radiological findings home discharges	94.23% 84.05%-98.79%	27.52% 22.52%-32.96%	1.30 1.18-1.43	0.21 0.07-0.64	18.49% 14.00%-23.70%	96.47% 90.03%-99.27%	3/350 (8.6%[c]); 3/52 (5.77%[d])
Relevant radiological findings home discharges	97.78% 88.23%-99.94%	27.54% 22.60%-32.92%	1.35 1.24-1.46	0.08 0.01-0.57	16.60% 12.33%-21.64%	98.82% 93.62%-99.97%	1/350 (0.29%[c]); 1/45 (2.22%[d])

Fig. 2 Proposed algorithm for performing Urgent non-traumatic cranial CT scans: Odds ratios of presenting complaint with predictive ability of Relevant clinical-radiological findings and/or Relevant radiological findings calculated by binary logistic regression adjusted for (**a**) age, sex, oncological patient, and operator and for (**b**) age, sex and operator. Percentage on the whole sample (**c**) and percentage on the endpoint (**d**). [Abbreviations: LR: likelihood ratio, PV: predictive value, RCRF: Relevant clinical-radiological findings (patient requiring admission or any relevant radiological findings is found on first CT scan or CT or MRI within the next three months), RRF: Relevant radiological findings (acute infarction, acute haemorrhage, mass, edema, unknown hydrocephalus)]

indicated if there is an associated focal neurological deficit; altered mental status; cognitive impairment; if the headache is different, sudden, and intense, or a new kind of headache in HIV-positive individuals (level of recommendation B [16]). The approach to the issue must be multidisciplinary. For instance, restructuring the medical record in emergency departments would reduce scarcely beneficial testing (from 31.3 to 13.9 low-value tests performed per-100 patient visits [10]). For our part, we will attempt to prospectively validate the algorithm derived from this research (Fig. 3).

Our work has several limitations. First, it is a single-center, retrospective study without external validation and, as such, must be taken with caution; however, it can serve as the basis for prospective analyses in other centers. Second, PC depend on how comprehensive the requesting physicians have been in taking patients' clinical histories. Therefore, we have not taken these physicians to be a variable that may have impacted our results. Third, the radiological reports were issued by emergency radiologists, on-call, or, exceptionally, on-call resident with at least three months of neuroradiological training. Nevertheless, an expert neuroradiologist reviewed the afternoon and night shift reports and their modifications were considered. Even so, only 5% of the double readings changed the medical approach. Fourth, we did not enquire as to whether other CT were performed at other centers after the first one, but very few would probably have gone unnoticed. Given how our healthcare system is organized, it is unlikely that people cared for in other centers would not have later returned to ours. Fifth, in an earlier work, we probed into the issues we face when a CT is requested without a suitable examination [17] and we cannot rule out the possibility that the CT findings influenced the PC later included in the medical record or whether the RRF may have then prompted a detailed neurological examination. This possible bias can be assessed in a future prospective study. Sixth, considering all the RRF as a single variable in the model may have limited the ability to determine the predictive capacity of certain PC for each type of RRF. However, our aim was to evaluate the diagnosis performance of each PC for any relevant, acute finding on the CT. Seven, when setting up the RCRF result variable, we did not distinguish between patients who were hospitalized or not for neurological causes. Nevertheless, to minimize false negatives with the algorithm and considering the potential severity of the symptoms when the patient ended up being hospitalized, we felt it was fitting to consider the CT to be adequate in all

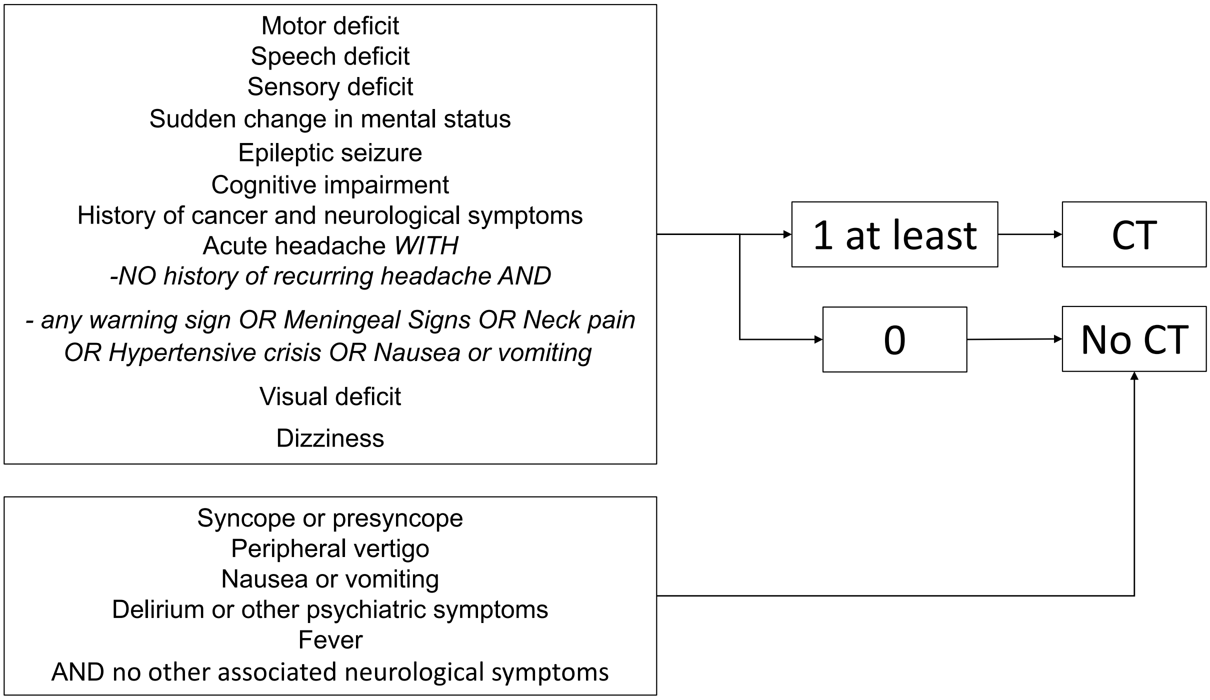


Fig. 3 Proposed algorithm derived from the work to test prospectively in our environment

those cases. This strategy has probably been detrimental to the discriminatory capacity of the algorithm to predict RRF, meaning that the safe margin to decrease the number of CT is likely to be greater than the one observed in patients hospitalized for non-neurological reasons. Finally, it is not clear what the acceptable level of risk or cost-effectiveness is for performing urgent cranial CTs. Although future developments will be needed to improve the results of the algorithm in terms of sensitivity and specificity, we thought worthy to make it known as a possible starting point for a better pretest clinical probability scale.

In short, our algorithm can be an approach to a pre-test clinical prediction scale for RRF on urgent cranial CT requested for non-traumatic causes. Its sensitivity and negative PV > 95% can contribute to significantly reducing unnecessary CT. While strategies must be applied in each local area after scrutinizing their own data [18], our results can be a valid starting point for others.

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Author contributions JMPM and JMGS conceived the study. JMPM, JMGS and MSC supervised the data collection. EOG, MSC, HOM, ECR and NICA, undertook recruitment of participating patients and data. JMPM and MBR analysed the data and chaired the data oversight committee. JMPM, JMGS and RVG drafted the manuscript, and all authors contributed substantially to its revision. JMPM takes responsibility for the paper.

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Data availability We would consider sharing our sample database, with appropriate permissions, if required.

Declarations

Ethics approval *This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the* Research Committee of our Institution (24 January 2022, internal code CETI 02/22).

Informed consent was waived by Research Committee of our Institution.

The manuscript does not contain figures of individual patients requiring their express consent.

Conflict of interests The authors declare no conflict of interest.

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