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Clinical significance of head CT scan in patients admitted to the emergency department with mild head trauma

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Abstract
Head computed tomography (CT) scan is the gold standard for early diagnosis of brain injuries in the Emergency Department (ED), but clinically important injuries after a mild head trauma (MHT) are rare. This study aims to evaluate the impact of head CTs on the management of patients presenting to the ED with MHT. In this prospective observational study, we enrolled adult patients admitted to the ED of a medium-size University Hospital for MHT. Patients were evaluated at the time of admission and then at 6-24-48-72 h (if still in the ED). A 90-day telephone follow-up was performed. The primary composite endpoint was a change in patients' management (hospitalization, modifications in pharmacotherapy or invasive treatments) following a CT. Between June 2021 and July 2023 we enrolled 508 patients. At least 1 CT was performed in 454 patients (89.4%), and the first CT revealed a brain injury in 87 (19.2%) of them. At least another CT was repeated in the first 24 h in 144 patients; delayed injuries were observed in 4 cases only, with no clinical impact. The cumulative number of CTs performed throughout the study was 620, but only 24 of them (3.9%) had a clinical impact, and none of the patients underwent neurosurgery. The incidence of intracranial injuries requiring admission or treatments was 4.5%. In conclusion, the incidence of brain injuries requiring treatment was very low, and most of the CTs had no clinical impact.

Keywords Mild head trauma · Mild traumatic brain injury · Mild head injury · Brain computed tomography · Emergency department

Introduction

Background

Head trauma is the main cause of death and disability in people under the age of 40 in industrialized countries [1] and contributes to 30% of trauma-related deaths [2]. Every year 2.5 million people are admitted to the Emergency Department (ED) because of head trauma in the USA [2] and 1.4 million in the UK [3]. In the European Union incidence and mortality are respectively 262/100′000 and 10.5/10′000 person-year [4] with an overall cost of 33 billion euros [5]. It has been estimated that 70–90% of all head traumas evaluated in the ED can be classified as mild, corresponding to a Glasgow Coma Scale score (GCS) between 13 and 15 [6]. Although the incidence of mild head trauma (MHT) is high, the overall mortality is very low (0.1%) [7].

Nevertheless, the definition of MHT is not univocal: for example, many authors use in their works a more restrictive definition of mild traumatic brain injury (mTBI) or minor/mild head injury which requires the presence of at least one additional finding among loss of consciousness < 30 min, retrograde amnesia < 24 h or transient altered mental status [8]; moreover, the inclusion of a GCS = 13 in the definition of "mild" is debated as such patients have higher mortality and worse neurological outcome [9–12].

The main goal of the emergency physician is to identify patients with MHT who could have evolving intracranial injuries and should then be tested with a brain computed tomography scan (CT). Over the years, multiple tools and guidelines have been developed to identify which patients need a CT [1, 13–18]. However, all these tools have shown a very high sensitivity but a very poor specificity in identifying

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brain injuries [15, 16]. Moreover, there is growing evidence that only a small percentage of all the brain injuries diagnosed in patients with MHT are actually clinically important (6.5–8.5%) and only 1.5–3.6% eventually need surgery [15, 16]. In 2005 Stiell et al. [15] proposed a definition of "clinically important" brain injuries based on radiological features: the group considered as clinically important every brain injury except a solitary contusion < 5 mm, a localized subarachnoid blood < 1 mm, a smear subdural hematoma < 4 mm or a closed depressed skull fracture not through the inner table (as long as the patient is neurologically intact).

The need to repeat a CT when the first examination is positive or when the patient has high risk factors is also debated. It has been suggested that patients on antiplatelet therapy (APT) are at high risk for injury expansion [19], and the same can be assumed for patients on oral anticoagulation (OAC). Nevertheless, the evidence is usually obtained from retrospective studies with heterogeneous populations and endpoints [20–22]. Similarly, it has been demonstrated that, when the first CT is negative, delayed injuries are extremely rare (0.0–6.0% in different studies) [23–30], usually with no clinical relevance [25, 26, 29–31]. Despite this evidences, many local protocols (including the one in force in our region) [32] still recommend the repetition of a CT in high-risk patients such as those on OAC.

Objectives

The aim of this study was to assess the impact of brain CTs on the management of patients with MHT. Secondary aims were to evaluate the adherence to key clinical decision tools (Canadian Computed Tomography Head Rule or CCTHR, New Orleans Criteria or NOC, National Emergency X-Ray Utilization Study II or NEXUS II) [13–16] and guidelines (National Institute for Health and Care Excellence or NICE, American College of Emergency Physician or ACEP) [1, 17, 18], to assess their effectiveness in detecting injuries requiring admission or therapy, and to identify new predictors of such injuries.

Materials and methods

Design and setting

This is a prospective observational monocentric study carried out in the ED of a medium-size Italian University Hospital. The study was approved by the local Ethical Committee (approval no. 636, 06/21/2021, CE 100/21) and conducted in accordance with the Declaration of Helsinki.

Patients admitted to the ED for MHT (defined as any blunt head trauma with a GCS between 13 and 15 at the first medical evaluation, as assessed by the attending physician) were enrolled unless they met one of the following exclusion criteria: age < 18 years, pregnancy, or refusal to provide a signed informed consent.

Data collection

Data about the mechanism of injury, the patient's personal medical history, previous neurological condition (modified Rankin Scale—mRS) and drugs history (with a focus on antithrombotic treatments, intended either as APT or OAC) were collected at the time of the first evaluation in the ED (t_0). A clinical examination focused on neurological signs and symptoms was performed at t_0 and after 6 (t_1), 24 (t_2), 48 (t_3), and 72 h (t_4), as long as patients were still in the ED or, after ED evaluation, had been transferred to its brief-intensive Observation Unit (OU). Information about CTs was collected during the 72-h study period. A 90-day telephone follow-up was performed.

Data were collected by emergency medicine residents and medical students and then anonymized and uploaded to a Research Electronic Data Capture platform (REDCap consortium, Vanderbilt University, TN, USA), hosted at the Università del Piemonte Orientale. This process was constantly supervised by the researchers, who, at the end of the study, double-checked the consistency between data and official medical records.

Outcomes

The primary composite endpoint was a change in patients' management decided by the emergency physician after finding a post-traumatic intracranial injury on a CT. The components of the primary endpoint were: (i) admission because of the brain injury, (ii) modifications in pharmacotherapy (reversal of anticoagulation, prolonged withdrawal of antithrombotic drugs, antiedema treatments) or (iii) invasive treatments (invasive ventilation or surgery).

Secondary endpoints were: (a) the single components of the primary endpoint; (b) brain injuries found at the first CT; (c) delayed injuries (intended as brain injuries seen in the following CTs, but not present at the first one); (d) the expansion at subsequent CTs of a brain injury; (e) a negative neurological outcome (defined as an increase in mRS attributable to head injury); (f) 90-day mortality from all causes and from head injury.

Analysis

The sample size was set at 483 patients and calculated based on the previous estimate of the incidence of clinically important injuries (8.5%) [15], by setting the confidence interval at 95% and the interval width at 0.05.

Patients' characteristics and clinical presentation factors were summarized using descriptive statistics. Continuous variables were reported as medians and interquartile ranges, while categorical variables were presented as counts and percentages. The comparisons between groups were performed through the Mann–Whitney U test for continuous variables and through the Fisher's exact test for categorical variables. The Cohen's κ coefficient was calculated to evaluate the adherence to the main tools and guidelines. Univariable logistic regression analyses were conducted to explore associations between candidates predictors and the outcome.

Statistical significance was set at two-tailed $P<0.05$.

Machine learning

A machine learning model was developed using clinically relevant predictors investigated at presentation. The selected variables included both demographic and clinical features, reflecting the patient's risk profile and presentation. We implemented and tested a suite of supervised machine learning algorithms to evaluate and compare the predictive performance. The characteristics of the developed models, as well as threshold optimization and calibration, model evaluation and comparison are reported in Supplementary Information S1 (Online Resource 2).

Predictor variables with more than 30% missing data were excluded from the analysis. For the remaining variables, missingness was addressed using a non-parametric hot-deck imputation method based on nearest-neighbor algorithms. This approach considered similarity patterns within the observed data to impute missing values in a stratified manner. The outcome variable was not imputed to preserve the validity of predictive modeling.

All analyses were performed using MedCalc 19.3.1 software (Mariakerke, Belgium), R version 3.4.2 and Python version 9.3.

Results

Characteristics of study subjects

Between June 2021 and July 2023, 510 patients were enrolled. Two were excluded because they left the ED before the physician's assessment.

Table 1 reports the main characteristics of the cohort (focusing on pre-event condition, risk factors and mechanism of injury) and the main data obtained through the first physical examination. The median time from trauma to triage was 80 [54–138] min, with 22 [8–59] min as the median waiting time before being assessed by a physician.

Head CT scans

At least one CT was performed in 454 patients (89.4%). The adherence to the most important decision tools or guidelines was limited: the best Cohen's κ was obtained for the NEXUS II (0.313). These tools and guidelines were confirmed to have a high sensitivity, but an overall very low specificity in identifying patients with a positive CT and, moreover, an intracranial injury that eventually has an impact on the patients' management. The adherence to the tools and guidelines and their diagnostic power are reported, respectively, in Supplementary Table S1 and S2 (Online Resource 1).

The CT was repeated at least once in 144 patients. The primary reason for repeating a scan was routine since most of the patients on OAC ($N=74/95$, 77.9%) or with a positive first scan ($N=73/87$, 83.9%) repeated the exam within 72 h (in 95.1% of cases within 24 h), regardless of their neurological status. Other reasons for repeating a CT were the recommendation of a neurosurgeon (38.3%) or a change in the neurological status (4.2%). Further data about the evolution of the patients' clinical features are reported in Supplementary Information S2 (Online Resource 2).

Primary composite endpoint and its components

Overall, data about 620 CTs were recorded in the study (1.2 CTs per patient).

Out of the 454 first CTs, only 11 (2.4%) had an impact on the patient's management (Fig. 1).

Considering all the 620 examminations, 24 of them (3.9%) had a clinical impact (Fig. 2). Considering the whole sample of patients, the incidence of injuries requiring admission or treatment was 4.5% ($N=23/508$).

Only one subject (0.2%) underwent endotracheal intubation (ETI) during the study, but no surgical intervention was performed. Twelve patients (1.9%) were admitted because of an intracranial injury (10 patients in neurosurgery, 1 in Semi-Intensive Care Unit, 1 in neurology). In 15 patients (2.4%) pharmacological treatments were modified or administered: in 9 cases antithrombotic drugs were withdrawn, in 6 cases antiedema treatments were given, and in 3 cases a reversal treatment for OAC was administered (more than one measure could follow a single scan).

The absolute number of CTs with clinical impact was higher at the first examination (11) and decreased during observation (1 at t_1, 8 at t_2, 4 at t_3, 0 at t_4), but the proportion of scans with clinical impact was higher at t_2 (6.1%) and t_3 (18.2%).

Patients taking OAC or APT were admitted or received treatment in a higher percentage of cases (54.2% vs. 44.0%), but this difference was not statistically significant ($P=0.442$). The same was found when OAC and APT were considered separately ($P=0.511$ and 0.805, respectively).

Table 1 Main characteristics of the overall sample

Patients and trauma characteristics ($N=508$)	Median [IQR] or N (%)	Symptoms and signs at presentation ($N=508$)	N (%)
Age (years)	71 [51–82]	**GCS**	
Sex (M/F)	262/246 (51.6%/48.4%)	15	492 (96.9%)
High dynamic trauma	56 (11.0%)	14	15 (3.0%)
Pedestrian struck	16 (3.1%)	13	1 (0.2%)
Ejection from vehicle	10 (2.0%)	**Headache**	58 (11.4%)
Fall from elevation > 1 m or > 5 stairs	30 (5.9%)	**Nausea**	69 (13.6%)
Non-high dynamic trauma	452 (89.0%)	**Vomiting**	38 (7.5%)
Accidental fall	328 (64.6%)	> 1 episode	7 (1.4%)
Fall due to dizziness, presyncope or syncope	70 (13.8%)	Projectile vomiting	1 (0.2%)
Seizure	4 (0.8%)	**Dizziness**	52 (10.2%)
Assault	13 (2.6%)	**Focal neurological deficit**†	1 (0.2%)
Traffic accident	10 (2.0%)	**Motor-cognitive impairment**†	9 (1.8%)
Hit by a fallen object	4 (0.8%)	**Speech impairment**†	11 (2.2%)
Unknown	23 (5.4%)	Unspecified	1 (0.2%)
Alcohol or drug intoxication	17 (3.3%)	Repetitiousness	8 (1.6%)
At least one among the following*	145 (28.5%)	Dysarthria	2 (0.4%)
Loss of consciousness	69 (13.6%)	Aphasia	0 (0.0%)
Amnesia	74 (14.6%)	**Sight impairment**†	10 (2.0%)
Transient altered mental status	73 (14.4%)	**Visible trauma above the clavicle**	393 (77.4%)
Cognitive impairment	37 (7.3%)	**Scalp hematoma**⁋	250 (49.2%)
Pre-event mRS		**Suspected open or depressed skull fracture**	11 (2.2%)
0	429 (84.4%)	**Signs of basal skull fracture**	8 (1.6%)
1	22 (26.5%)	Hemotympanum	4 (0.8%)
2	23 (27.7%)	Racoon eyes	3 (0.6%)
3	15 (18.1%)	Battle's sign	0 (0.0%)
4	19 (22.9%)	CSF otorrhea or rinorrhea	1 (0.2%)
Oral anticoagulation	95 (18.7%)	**Behavioral abnormalities**	7 (1.4%)
Antiplatelet therapy	118 (23.2%)	**Seizure**	1 (0.2%)

IQR interquartile range, *M* males, *F* females, *mRS* modified Rankin Scale. *GCS* Glasgow Coma Scale score, *CSF* cerebrospinal fluid

*In the literature, patients presenting at least one among loss of consciousness, amnesia or witnessed transient altered mental status are often classified as high risk patients [1] or included in more restrictive definitions of head trauma such as mild Traumatic Brain Injury (mTBI) or minor head injury [8, 13, 14]

†New-onset neurological signs potentially related to brain injuries

⁋Scalp hematoma refers to swelling secondary to hematoma formation over any portion of the bony calvarium (excluding hematomas limited to the face and neck), as it is defined in the NEXUS II criteria [16]

Secondary endpoints

Brain injuries found at the first CT

A brain injury was observed at the first CT in 87 patients (17.1% of the overall sample, 19.2% of patients with at least one CT). Figure 3 shows the prevalence of each type of intracranial lesion. According to the definition proposed by Stiell et al. [15], 40 patients had a "clinically important" injury (7.9% of the overall sample, 8.8% of all the patients with at least one CT, and 46.0% of the patients with a positive first CT).

The percentage of positive CTs was not significantly different in patients taking OAC (15.8% with OAC vs. 20.1% without, $P=0.428$) or APT (21.6% with APT vs. 18.3% without, $P=0.535$).

Delayed injuries

A delayed injury was identified in four patients (0.8% of the overall sample): in three cases brain petechiae appeared at the second scan (in 1 patient at t_1 and in 2 patients at t_2), while the remaining patient had a subarachnoid hemorrhage and intraventricular hemorrhage.

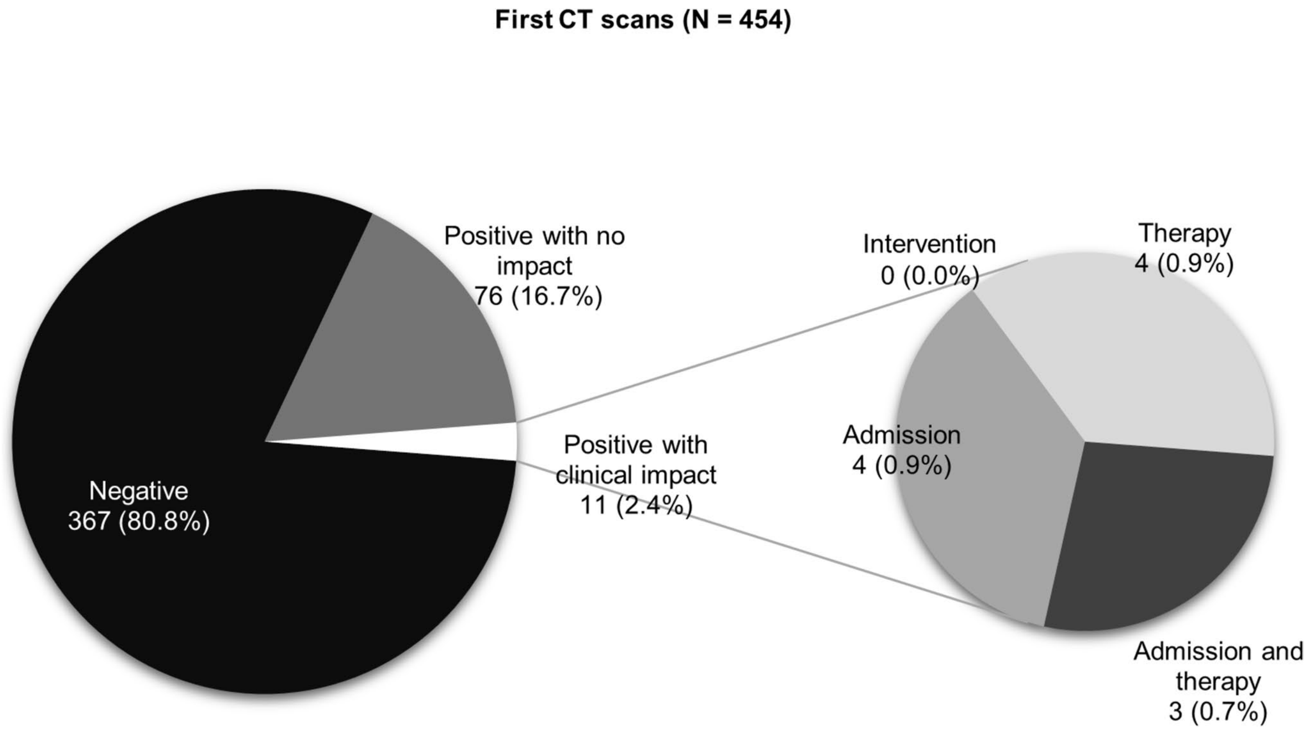

Fig. 1 Analysis of data obtained from the first CT scan of every patient

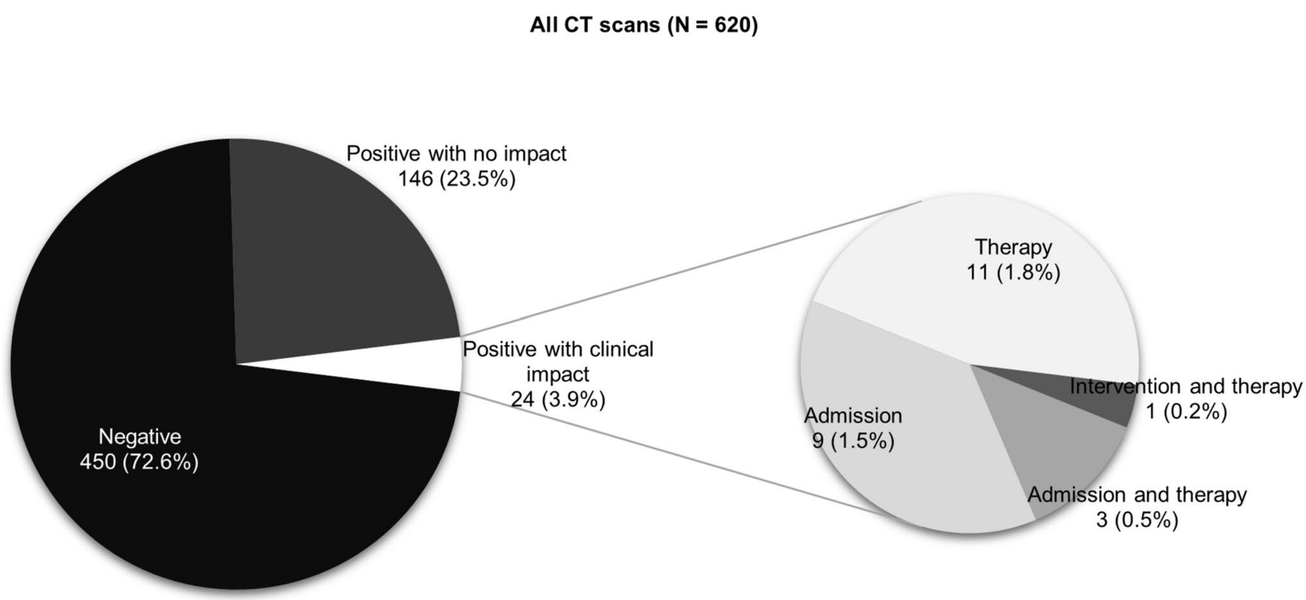

Fig. 2 Analysis of data obtained from all the CT scans performed in the study

Finding a delayed injury had a clinical impact only in 1/4 cases (OAC was withdrawn but not reversed).

The incidence of delayed injuries was not significantly different in patients on antithrombotic treatments (neither APT nor OAC).

Injury expansion

Injury expansion was observed in 13 of the 87 patients with a first positive CT (14.9%): in 2 patients the first CT was already significant, and no further measure was

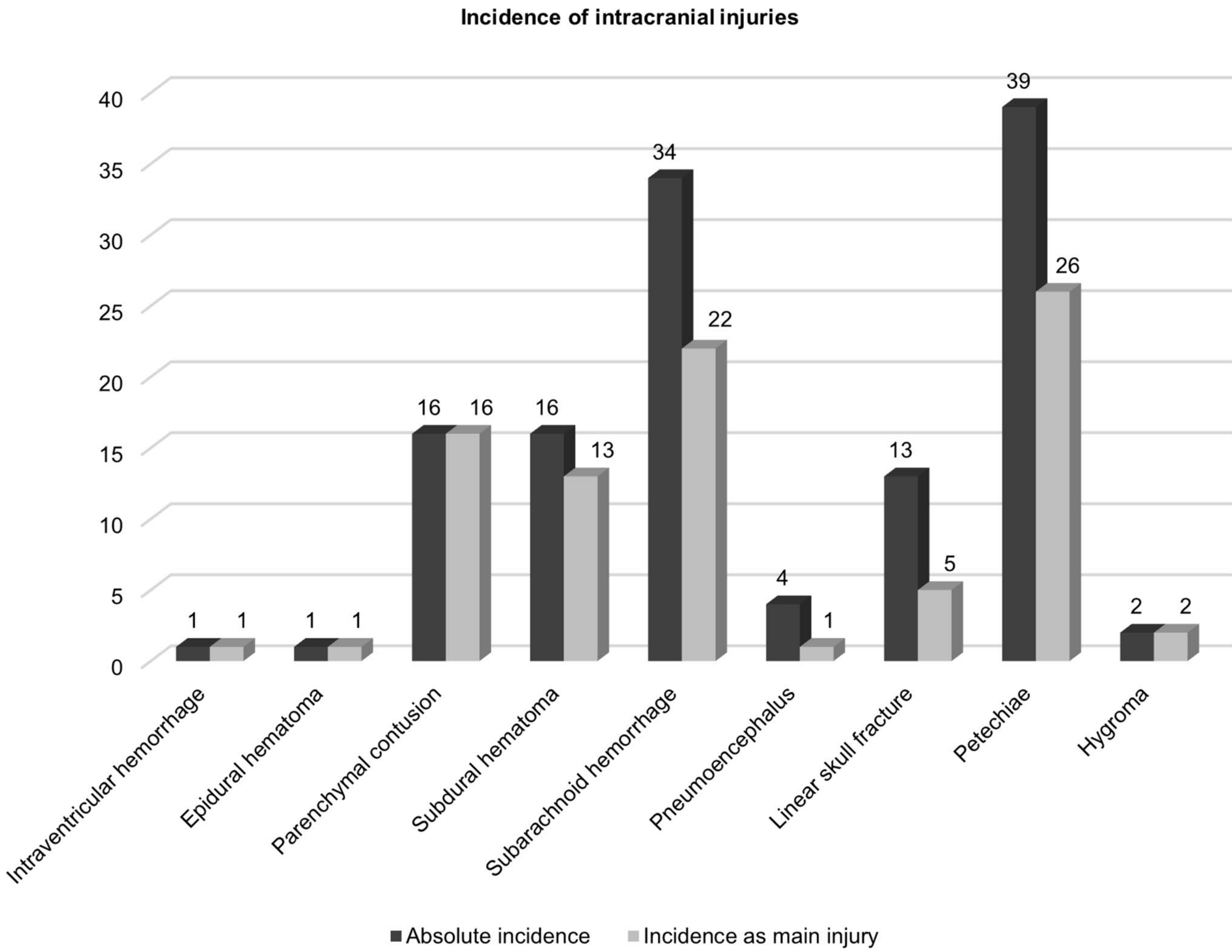

Fig. 3 Black bars indicate the absolute incidence of each lesion (in fact, different lesions could be seen in the same CT scan), while light bars indicate the incidence of each lesion as the main injury of a single CT scan. On a pathophysiological basis, intracranial injuries were given the following order of decreasing severity and importance: intraventricular hemorrhage, epidural hematoma, parenchymal contusion, subdural hematoma, subarachnoid hemorrhage, pneumoencephalus, linear skull fracture, petechiae, hygroma. CT = computed tomography

implemented, 3 patients were admitted, in 3 patients antithrombotic treatment was withdrawn, and 1 patient underwent ETI.

The incidence of injury expansion was not significantly different in patients on antithrombotic treatments (neither APT nor OAC).

Neurological outcome

Patients stayed in the ED 5 [4–8] h before being discharged or moved to the OU or an ordinary ward. Patients moved to the OU ($N = 168$) stayed in this setting for 23 [19–39] h. The cumulative length-of-stay in our department was therefore 20 [5–31] h. Figure 4 shows the outcome of patients in the ED and in the OU. Other information about patients' outcome is reported in Supplementary Information S3 (Online Resource 2).

Out of 508 patients, 134 (26.4%) were lost to follow-up. The mRS increased compared to baseline in 43 patients (11.7%), but only in 6 (1.6%) did this negative outcome result from a brain injury. The analysis showed no association between a TBI-related negative outcome and specific trauma characteristics or signs and symptoms at presentation. Patients with an increase in the mRS at 90 days were significantly older (68 vs. 78 years, $P = 0.023$), but no difference in terms of age was found between patients with or without a negative neurological outcome attributable to a brain injury (69 vs. 68 years, $P = 0.530$). A positive CT scan was associated with a TBI-related negative neurological outcome (11.5% vs. 1.2%, $P = 0.0002$); and this association appeared stronger considering patients with clinically

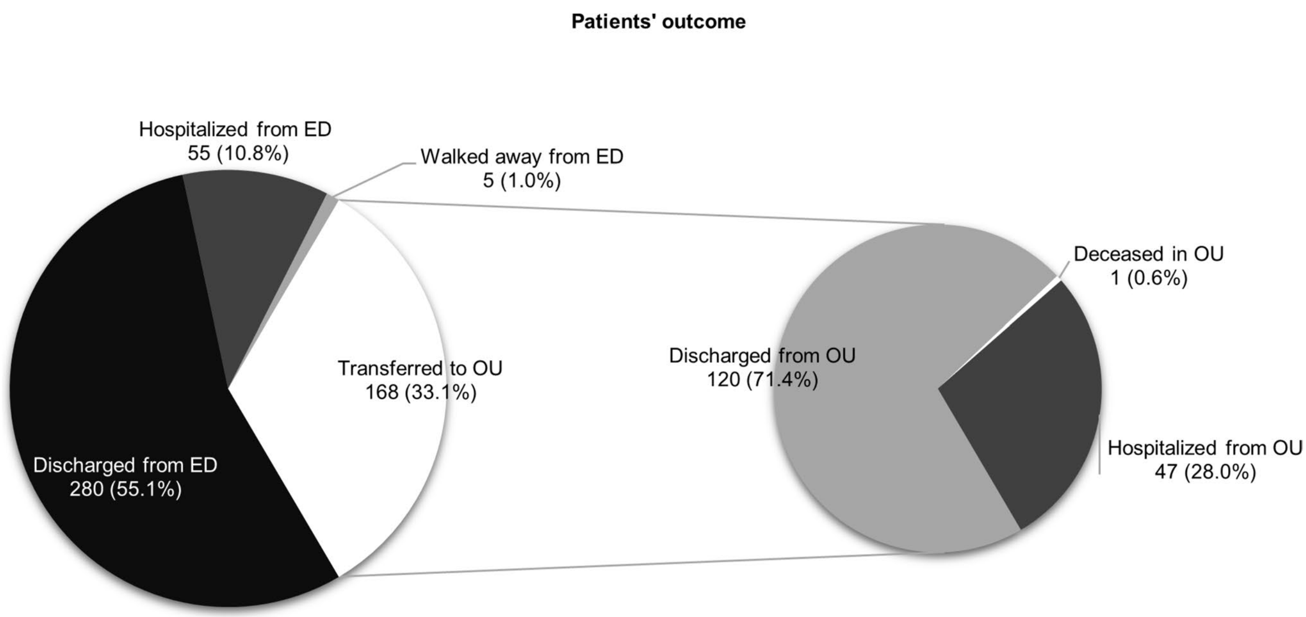

Fig. 4. Outcome of patients in the ED and in the OU. *ED* Emergency Department; *OU* Observation Unit

important brain injuries (23.3% vs. 10.6%, $P<0.0001$) or with brain injuries requiring admission or treatments (25.0% vs. 2.0%, $P<0.0001$). Other information obtained at follow-up is reported in Supplementary Information S4 (Online Resource 2).

90-day mortality

Six patients died in hospital (1 in the OU), but only one death was TBI related (further information about this patient is reported in Supplementary Information S5 in Online Resource 2). Thirteen patients died after being discharged within 90 days from enrollment, but the review of these cases showed that none of these deaths was TBI-related. This is partially demonstrated by the fact that both in-hospital and 90-day mortality rates were not significantly higher in patients with a first positive CT scan or a clinically important brain injury. On the other hand, patients with at least one CT scan with clinical impact had a higher in-hospital mortality (8.3% vs. 0.9%, $P=0.030$). Age was significantly higher in patients who died in hospital (70 vs 82 years, $P=0.034$) or within 90 days (69 vs. 85 years, $P<0.0001$).

Machine learning predictors of clinically important injuries

Random forest consistently demonstrated the highest predictive performance, regardless of preprocessing.

According to the variable importance plot shown in Fig. 5, the most important covariate was the loss of consciousness, followed by age and antithrombotic treatments. The model achieved high discrimination, as demonstrated by balanced accuracy values above acceptable training and test set thresholds. The ROC AUC also confirmed the model's strong classification performance.

Further information about all the tested models is reported in the Supplementary Information (Supplementary Information S6 in Online Resource 2 and Fig. S1 in Online Resource 3).

Discussion

This study investigated the actual impact of head CTs on the clinical management of patients with MHT, in an effort to move the focus from the identification of any brain injury to the identification of brain injuries that actually modify the clinical management of the patient. Specifically, we identified three clinically impacting "interventions": admission because of a brain injury (and mainly its extension and effects on the patient's condition), invasive procedures (e.g. surgical procedures or simply ETI because of neurological deterioration), and pharmacological treatments (including reversal or modifications of ongoing antithrombotic therapies).

The results show that our current protocols [32] lead to performing more than one CT per patient (specifically 1.2), but only 3.9% of these examinations had some clinical relevance. This percentage includes also patients who were admitted, but in which no surgical treatment was performed: the percentage of "treated patients" is therefore even lower. This remarks how, in patients with MHT, not only

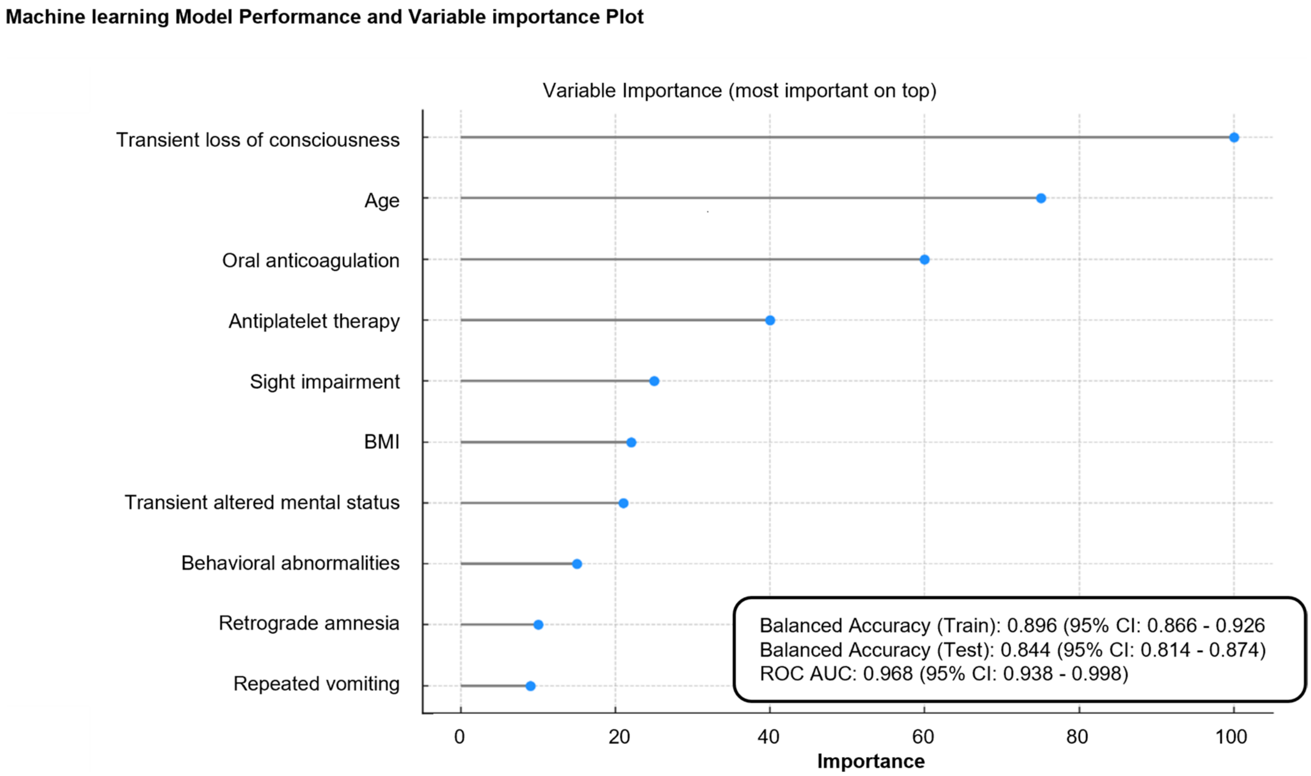

Fig. 5 Variable importance ranking and model performance metrics for the best-performing model in the machine learning classification task. Higher ROC and balanced accuracy values indicate robust discriminatory ability across train and test sets. *BMI* Body Mass Index, *ROC AUC* Receiver-Operating Characteristic Area Under the Curve

intracranial injuries are rare, but even when present their impact is very low [15, 16].

In fact, only one patient required an invasive treatment (ETI). However, despite meeting the criteria for MHT, this patient showed at presentation many warning signs that clearly suggested the presence of a clinically important injury (unknown trauma dynamic, GCS = 14, altered mental status, cognitive motor slowing, speech impairment): no emergency physician would probably have any doubt about performing a CT in such a patient (Supplementary Information S5 in Online Resource 2).

In 15 patients, either a pharmacological treatment was administered (mainly a reversal treatment for OAC) or the patient's usual therapy was modified by withdrawing an antithrombotic drug. Despite the obvious bias that only patients taking OAC were eligible to receive reversal therapies, these patients did not have a significantly higher rate of "meaningful" CTs. In fact, reversal therapies were administered only in 3 out of 13 candidates, probably because the physician did not consider the intracranial injury at risk of expansion. However, the 90-day follow-up showed that this choice had no negative impact on the outcome. This does not mean that antithrombotic drugs are not a risk factor for important injuries (as confirmed by the machine learning model that identified OAC and APT as potential predictors of a "significant" brain injury), but that also in such patients other variables should be considered, and that the indiscriminate administration of reversal treatments to patients on OAC with a positive scan is not needed.

On the other hand, the results confirmed that delayed injuries are rare events (2.8% of all the patients who repeated a CT) that usually have no impact on the patient's clinical outcome (0.7% of all the patients who repeated a CT). Injury expansion was a more frequent event (14.9%), but the reviewing of every single case showed that most of the decisions taken after the second scan were already justified by the results of the first one (such as the withdrawing of OAC in patients with a positive scan).

The machine learning model identified loss of consciousness following a head trauma as the most important predictor of intracranial injuries requiring admission or treatment. As a matter of fact, loss of consciousness is already included in most of the diagnostic tools and guidelines as a reason to perform a CT scan, as well as all the other potential predictors identified by the model and reported in the variable importance plot displayed in Fig. 5. However, the model showed an overall poor performance, probably because of the small number of positive CTs with clinical impact, and this limits the interpretation of its results. The simplest explanation could be that the items included in those tools are actually the most accurate predictors, but they should be combined and weighed in a more sophisticated diagnostic score.

Limitations

A major limitation affecting this study, and more generally the current literature on this topic, is related to the lack of consensus about the definition of head trauma. As previously outlined, many authors use in their works the more restrictive definition of mTBI or minor/mild head injury that includes only patients reporting loss of consciousness, amnesia, or a witnessed transient altered mental status. Others do not use a specific term, but refer in general to head trauma patients with or without those specific features, such as the NICE Guidelines [1]. In our study, we decided to adopt the most comprehensive definition to increase the generalizability of the results, but we also decided to specifically address the distinction between MHT and this more restrictive definition because it remains widely used and two of the investigated diagnostic tools (NOC and CCHTR) are only validated for patients who meet those criteria [13, 14]. We acknowledge, however, that given the absence of a universally accepted definition, any choice made in this setting may be subject to debate.

The study took place during the COVID-19 pandemic. During viral outbreaks (e.g., in autumn–winter 2021–2022 and spring 2022) resources in our ED were reorganized to face the emergency, and consecutive enrollment was not always feasible.

Our ED has an OU where patients can be kept for 24–48 h. These patients are not considered as hospitalized in our institution; therefore, when the protocol was designed, admission to the OU was not included in the composite endpoint. This could be a bias, since other institutions/countries may have different organizations, and an observation of 24–48 h may be considered as hospitalization. However, our local guideline still suggests observing all patients taking OAC; if all these patients had been considered as hospitalized, the data would have probably been even more biased.

The sample size was calculated on the basis of a previous estimate of the incidence of clinically important injuries (8.5%). The results confirmed this estimate since the incidence of clinically important injuries was 7.8% in our study. However, having a "clinically important" injury according to the definition proposed by Stiell et al. [15] did not reflect the need of admission or treatments, since the incidence of such injuries was significantly lower in the study (4.5%). Therefore, the limited number of "events" reduced the power of the analysis, especially of the machine learning model, and may restrict the generalizability of its findings. Further external validation in larger cohorts is necessary to confirm the model's performance across different clinical settings.

Inter-observer variability may limit data reliability since the same patient could be evaluated by different researchers throughout the protocol time points.

The data obtained from the telephone follow-up are limited by the high proportion of patients lost to follow-up (26.4%).

Conclusions

This study shows that only a small percentage of all the CTs performed in MHT have an impact on the patients' management: in fact, the incidence of brain injuries requiring admission or treatments is very low. The results confirmed that delayed injuries and injury expansion are rare events that usually do not impact on the patient's outcome: the CT should not be routinely repeated if the neurological status is intact or unchanged. Larger studies are needed to identify predictors of injuries requiring admission or treatments to reduce the number of unnecessary CTs.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11739-026-04314-0.

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Author contributions MaBal conceived and designed the study, performed data analysis and interpretation, and wrote the manuscript. FG, LM and DA performed data analysis and interpretation and contributed to writing the manuscript. DL, AR, LR, DU, AG, MA, FMG, CC, MiBel, and GI acquired the data and contributed to data analysis. MaBel, PPS, LMC, GCA, FP participated in data interpretation and contributed to writing the manuscript. All authors reviewed and approved the manuscript.

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Data availability The data that support the findings of this study are not openly available due to reasons of sensitivity. They are stored in anonymised form on the Research Electronic Data Capture platform (REDCap consortium, Vanderbilt University, TN, USA) hosted at the Università del Piemonte Orientale and are available from the corresponding author upon reasonable request.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the local Ethical Committee (approval n. 636, 06/21/2021, CE 100/21).

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Head injury: assessment and early management (NICE Guideline, NG232). London: National Institute for Health and Care Excellence (NICE); 2023 May 18.
2. Taylor CA, Bell JM, Breiding MJ, Xu L (2017) Traumatic brain injury-related emergency department visits, hospitalizations, and deaths - United States, 2007 and 2013. MMWR Surveill Summ 66(9):1–16. https://doi.org/10.15585/mmwr.ss6609a1
3. NICE Guideline, CG176 (2019) Head injury: assessment and early management. National Institute for Health and Care Excellence (NICE), London
4. Peeters W, van den Brande R, Polinder S, Brazinova A, Steyerberg EW, Lingsma HF, Maas AI (2015) Epidemiology of traumatic brain injury in Europe. Acta Neurochir (Wien) 157(10):1683–1696. https://doi.org/10.1007/s00701-015-2512-7
5. Olesen J, Gustavsson A, Svensson M, Wittchen HU, Jönsson B, CDBE2010 study group, European Brain Council (2012) The economic cost of brain disorders in Europe. Eur J Neurol 19(1):155–162. https://doi.org/10.1111/j.1468-1331.2011.03590.x
6. Cassidy JD, Carroll LJ, Peloso PM, Borg J, von Holst H, Holm L, Kraus J, Coronado VG, WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury (2004) Incidence, risk factors and prevention of mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on mild traumatic brain injury. J Rehabil Med 43(Suppl):28–60. https://doi.org/10.1080/16501960410023732
7. af Geijerstam JL, Oredsson S, Britton M, Investigators OS (2006) Medical outcome after immediate computed tomography or admission for observation in patients with mild head injury: randomised controlled trial. BMJ 333(7566):465. https://doi.org/10.1136/bmj.38918.669317.4F
8. Lefevre-Dognin C, Cogné M, Perdrieau V, Granger A, Heslot C, Azouvi P (2021) Definition and epidemiology of mild traumatic brain injury. Neurochirurgie 67(3):218–212. https://doi.org/10.1016/j.neuchi.2020.02.002
9. Culotta VP, Sementilli ME, Gerold K, Watts CC (1996) Clinicopathological heterogeneity in the classification of mild head injury. Neurosurgery 38(2):245–250. https://doi.org/10.1097/00006123-199602000-00002
10. Servadei F, Teasdale G, Merry G, Neurotraumatology Committee of the World Federation of Neurosurgical Societies (2001) Defining acute mild head injury in adults: a proposal based on prognostic factors, diagnosis, and management. J Neurotrauma 18(7):657–664. https://doi.org/10.1089/089771501750357609
11. Uchino Y, Okimura Y, Tanaka M, Saeki N, Yamaura A (2001) Computed tomography and magnetic resonance imaging of mild head injury–is it appropriate to classify patients with Glasgow Coma Scale score of 13 to 15 as "mild injury"? Acta Neurochir (Wien) 143(10):1031–1037. https://doi.org/10.1007/s007010170008
12. Valente JH, Anderson JD, Paolo WF, Sarmiento K, Tomaszewski CA, Haukoos JS, et al. (2023) Clinical policy: critical issues in the management of adult patients presenting to the emergency department with mild traumatic brain injury: approved by ACEP Board of Directors, February 1, 2023 Clinical Policy Endorsed by the Emergency Nurses Association (April 5, 2023). 81(5):e63-e105. https://doi.org/10.1016/j.annemergmed.2023.01.014
13. Stiell IG, Wells GA, Vandemheen K, Clement C, Lesiuk H, Laupacis A, McKnight RD, Verbeek R, Brison R, Cass D, Eisenhauer ME, Greenberg G, Worthington JR (2001) The canadian CT head rule for patients with minor head injury. Lancet 357(9266):1391–1396. https://doi.org/10.1016/s0140-6736(00)04561-x
14. Haydel MJ, Preston CA, Mills TJ, Luber S, Blaudeau E, DeBlieux PM (2000) Indications for computed tomography in patients with minor head injury. N Engl J Med 343(2):100–105. https://doi.org/10.1056/NEJM200007133430204
15. Stiell IG, Clement CM, Rowe BH, Schull MJ, Brison R, Cass D, Eisenhauer MA, McKnight RD, Bandiera G, Holroyd B, Lee JS, Dreyer J, Worthington JR, Reardon M, Greenberg G, Lesiuk H, MacPhail I, Wells GA (2005) Comparison of the canadian CT head rule and the new orleans criteria in patients with minor head injury. JAMA 294(12):1511–1518. https://doi.org/10.1001/jama.294.12.1511
16. Mower WR, Gupta M, Rodriguez R, Hendey GW (2017) Validation of the sensitivity of the National Emergency X-Radiography Utilization Study (NEXUS) head computed tomographic (CT) decision instrument for selective imaging of blunt head injury patients: an observational study. PLoS Med 14(7):e1002313. https://doi.org/10.1371/journal.pmed.1002313
17. Jagoda AS, Bazarian JJ, Bruns JJ, Cantrill SV, Gean AD, Howard PK et al (2008) Clinical policy: neuroimaging and decision-making in adult mild traumatic brain injury in the acute setting. Ann Emerg Med 52(6):714–748. https://doi.org/10.1016/j.annemergmed.2008.08.021
18. Vos PE, Alekseenko Y, Battistin L, Ehler E, Gerstenbrand F, Muresanu DF, Potapov A, Stepan CA, Traubner P, Vecsei L, von Wild K, European Federation of Neurological Societies (2012) Mild traumatic brain injury. Eur J Neurol 19(2):191–198. https://doi.org/10.1111/j.1468-1331.2011.03581.x
19. Fabbri A, Servadei F, Marchesini G, Bronzoni C, Montesi D, Arietta L, Società Italiana di Medicina d'Emergenza Urgenza Study Group (2013) Antiplatelet therapy and the outcome of subjects with intracranial injury: the Italian SIMEU study. Crit Care 17(2):R53. https://doi.org/10.1186/cc12575
20. Stippler M, Smith C, McLean AR, Carlson A, Morley S, Murray-Krezan C, Kraynik J, Kennedy G (2012) Utility of routine follow-up head CT scanning after mild traumatic brain injury: a systematic review of the literature. Emerg Med J 29(7):528–532. https://doi.org/10.1136/emermed-2011-200162
21. Almenawer SA, Bogza I, Yarascavitch B, Sne N, Farrokhyar F, Murty N, Reddy K (2013) The value of scheduled repeat cranial computed tomography after mild head injury: single-center series and meta-analysis. Neurosurgery 72(1):56–62. https://doi.org/10.1227/NEU.0b013e318276f899. (**discussion 3-4**)
22. Reljic T, Mahony H, Djulbegovic B, Etchason J, Paxton H, Flores M, Kumar A (2014) Value of repeat head computed tomography after traumatic brain injury: systematic review and meta-analysis. J Neurotrauma 31(1):78–98. https://doi.org/10.1089/neu.2013.2873
23. Menditto VG, Lucci M, Polonara S, Pomponio G, Gabrielli A (2012) Management of minor head injury in patients receiving oral anticoagulant therapy: a prospective study of a 24-hour

observation protocol. Ann Emerg Med 59(6):451–455. https://doi.org/10.1016/j.annemergmed.2011.12.003
24. McCammack KC, Sadler C, Guo Y, Ramaswamy RS, Farid N (2015) Routine repeat head CT may not be indicated in patients on anticoagulant/antiplatelet therapy following mild traumatic brain injury. West J Emerg Med 16(1):43–49. https://doi.org/10.5811/westjem.2014.10.19488
25. Cohn B, Keim SM, Sanders AB (2014) Can anticoagulated patients be discharged home safely from the emergency department after minor head injury? J Emerg Med 46(3):410–417. https://doi.org/10.1016/j.jemermed.2013.08.107
26. Chauny JM, Marquis M, Bernard F, Williamson D, Albert M, Laroche M, Daoust R (2016) Risk of delayed intracranial hemorrhage in anticoagulated patients with mild traumatic brain injury: systematic review and meta-analysis. J Emerg Med 51(5):519–528. https://doi.org/10.1016/j.jemermed.2016.05.045
27. Verschoof MA, Zuurbier CCM, de Beer F, Coutinho JM, Egginк EA, van Geel BM (2018) Evaluation of the yield of 24-h close observation in patients with mild traumatic brain injury on anticoagulation therapy: a retrospective multicenter study and meta-analysis. J Neurol 265(2):315–321. https://doi.org/10.1007/s00415-017-8701-y
28. Uccella L, Zoia C, Perlasca F, Bongetta D, Codecà R, Gaetani P (2016) Mild traumatic brain injury in patients on long-term anticoagulation therapy: do they really need repeated head CT scan? World Neurosurg 93:100–103. https://doi.org/10.1016/j.wneu.2016.05.061
29. Campiglio L, Bianchi F, Cattalini C, Belvedere D, Rosci CE, Casellato CL, Secchi M, Saetti MC, Baratelli E, Innocenti A, Cova I, Gambini C, Romano L, Oggioni G, Pagani R, Gardinali M, Priori A (2017) Mild brain injury and anticoagulants: less is enough. Neurol Clin Pract 7(4):296–305. https://doi.org/10.1212/CPJ.0000000000000375
30. Hickey S, Hickman ZL, Conway J, Giwa A (2021) The effect of direct oral anti-coagulants on delayed traumatic intracranial hemorrhage after mild traumatic brain injury: a systematic review. J Emerg Med 60(3):321–330. https://doi.org/10.1016/j.jemermed.2020.10.037
31. Connon FF, Namdarian B, Ee JL, Drummond KJ, Miller JA (2011) Do routinely repeated computed tomography scans in traumatic brain injury influence management? A prospective observational study in a level 1 trauma center. Ann Surg 254(6):1028–1031. https://doi.org/10.1097/SLA.0b013e318219727f
32. GdL interaziendale Area Piemonte Nord Est (2016) Gestione terapia anticoagulante/antiaggregante nel paziente neurologico. https://www.aslvco.it/wp-content/uploads/2020/05/8041260GESTIONE_NEUROLO.pdf. Accessed 12 September 2025

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