



HAL
open science

External validation of pittsburgh infant brain injury score in a French pediatric study

Cécile Oger, Audrey Grain, Elise Launay, Christèle Gras-Leguen, Fleur Lorton,
Pauline Scherdel

► **To cite this version:**

Cécile Oger, Audrey Grain, Elise Launay, Christèle Gras-Leguen, Fleur Lorton, et al.. External validation of pittsburgh infant brain injury score in a French pediatric study. *Archives de Pédiatrie*, 2025, 32 (3), pp.157 - 162. <10.1016/j.arcped.2024.11.007>. <hal-05240657>

HAL Id: hal-05240657

<https://hal.science/hal-05240657v1>

Submitted on 4 Sep 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons CC BY 4.0 - Attribution - International License



Research paper

External validation of pittsburgh infant brain injury score in a French pediatric study

Cécile Oger^a, Audrey Grain^{b,c,d,*}, Elise Launay^{a,c}, Christèle Gras-Leguen^{a,c}, Fleur Lorton^{a,c}, Pauline Scherdel^c^a CHU Nantes, Pediatric emergency department F-44000 Nantes, France^b CHU Nantes, Pediatric hematology and oncology department F-44000 Nantes, France^c Nantes Université, CHU Nantes, INSERM, FEA, CIC 1413 F-44000 Nantes, France^d CRCl²NA, Nantes Université, Inserm UMR 1307, CNRS UMR 6075, Université d'Angers F-44000 Nantes, France

ARTICLE INFO

Keywords:

Abusive head trauma
Head CT
Sensitivity and specificity
Clinical prediction rule

ABSTRACT

Background: Abusive Head Trauma (AHT) is a leading cause of morbidity and mortality in infants requiring rapid neuroimaging performance and prognostic rapid diagnosis. The Pittsburgh Infant Brain Injury Score (PIBIS) clinical prediction rule (CPR) was derived to identify infants most likely to present brain injury, whose diagnosis would benefit from head CT. Our study aimed to externally validate the PIBIS CPR in a pediatric French population.

Methods: A retrospective study was conducted in a French pediatric emergency department between 2015 and 2017. We included all consecutive infants who underwent a neurological imaging. Medical data were collected, and PIBIS score was determined, both retrospectively.

Results: We included 129 infants among which 33 cases (including 20 with a diagnosis of AHT). The sensitivity and specificity of the PIBIS CPR were 75.8 % (95 % CI 57.7–88.9) and 61.4 % (51.0–71.2) and negative and positive predictive values 88.1 % (77.8–94.7) and 40.3 % (33.0–48.2). Among the 20 infants with a diagnosis of AHT, 19 (95.0 %) were correctly identified by the PIBIS CPR.

Conclusion: Our external validation study found a lower diagnostic value of the PIBIS CPR than in the original study. This argues for adding biomarkers to improve its performance, notably in the context of suspected AHT.

1. Introduction

Abusive head trauma (AHT), formerly known as “shaken baby syndrome” or “whiplash syndrome”, is defined by the French High Authority for Health as a cephalic injury caused by violent shaking that can be associated with a direct cephalic impact [1]. The shaking induces intracranial bleeding, mostly plurifocal subdural hematomas due to breakdown of bridging veins [2,3]. These hematomas may be associated with retinal bleeding, spinal cord injury and bone fractures [3]. Because of its severity and frequency, AHT is a major public health issue [4]. It may lead to death in a physical abuse setting and is a cause of morbidity and mortality in infants under age 1 year [2,5,6].

The mortality rate of AHT is high, from 7 % to 27 % depending on the published series [7–10]. The incidence of neurological sequelae (epilepsy, motor or cognitive deficits, behavioral disorders, learning disabilities) ranges from 63 % to 85 % of survivors [9,11,12]. The estimated

annual incidence is from 14 to 38 per 100,000 infants under age 1 year [10,13–17], but this is probably underestimated [18,19]. First, symptoms of AHT can be moderate and do not always lead to a medical consultation. Second, AHT could be difficult to diagnose, as described by Jenny *et al* [20]. Indeed, the authors showed that 30 % of children with a diagnosis of AHT had already been examined by a physician for similar symptoms during the previous days, weeks or months before admission. Therefore, 30 % of shaken babies were likely not identified [20]. More recent studies showed that 13 % to 31 % of pediatric victims of abuse have a history of missed diagnosis [21,22]. However, delay in diagnosis represents a major risk factor for further additional abuse for these infants. Indeed, in a study based on confessions from perpetrators, shaking was repeated in 55 % of cases [2].

Difficulties in diagnosing AHT could be related to the absence of reported head trauma or shaking by perpetrators [23]. Moreover, the broad and non-specific clinical spectrum [24] and the need to perform

* Corresponding Author. pediatric oncology and hematology department, CHU Nantes F-44000 Nantes, France.

E-mail address: Audrey.grain@chu-nantes.fr (A. Grain).

<https://doi.org/10.1016/j.arcped.2024.11.007>

Received 9 November 2023; Received in revised form 14 August 2024; Accepted 19 November 2024

Available online 17 February 2025

0929-693X/© 2025 The Author(s). Published by Elsevier Masson SAS on behalf of Société française de pédiatrie. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

head computed tomography (CT) to formally identify traumatic cerebral lesions induce additional difficulties in diagnosing AHT. Head CT is indeed the most sensitive and specific paraclinical exam for the diagnosis of subdural hematoma. It is also the imaging most easily available in an emergency situation [9]. However, head CT must be used with caution, especially in young children, considering the radiation exposure and potential risk of secondary carcinogenesis [25,26]. Furthermore, organization of such neuroimaging can sometimes be challenging in overcrowded pediatric emergency departments (EDs), considering the potential need for sedation.

In this context, the Pittsburgh Infant Brain Injury Score (PIBIS) clinical prediction rule (CPR) was derived to prompt the treating physician to consider the brain as a possible etiology of an infant's symptoms. It aims to help clinicians in pediatric EDs better select infants most likely to present brain injury, whose diagnosis would benefit from head CT. This CPR was externally validated in a prospective, multi-centric US study that enrolled 1,042 individuals (216 cases and 826 controls) in EDs of three children's hospitals from 2006 to 2014. Included patients were children who appeared well and for whom brain injury may not be part of the initial differential diagnosis (presenting apnea or vomiting without diarrhea, seizure, soft tissue swelling of the scalp, bruising). The PIBIS CPR was evaluated for its ability to target infants presenting both traumatic and non-traumatic cephalic abnormalities. This study had encouraging results, with a sensitivity for predicting neuro-radiological abnormalities of 93.3 % (95 % confidence interval [CI] 89.0–96.3) and a specificity 53.0 % (95 % CI 49.3–57.1) [27]. Nevertheless, this innovative study was limited by its convenience sample and the fact that neurological imaging was not performed in all participants, which led to potential misclassification among control patients. It also did not allow for strong conclusions on the impact of the PIBIS CPR on identifying traumatic and non-traumatic cerebral lesions.

Our study aimed to validate the PIBIS CPR in a French pediatric population by assessing its clinical performance in predicting abnormal neuroimaging results in children with moderate symptoms of neurological impairment, particularly in a context of suspected AHT.

2. Material and methods

2.1. Study design and setting

We conducted a retrospective external validation study in the pediatric ED of the University Hospital of Nantes between January 1, 2015 and December 31, 2017. The procedures used in this study adhere to the tenets of the Declaration of Helsinki. The protocol was approved by the local ethics committee of the Nantes University Hospital (RC16_0175). The parental information for the study was displayed on billboards placed in all public places in the hospital. The message on billboards indicated that data collected for routine medical care could be reused for observational studies if parents did not express their opposition to this use. We followed the Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis (TRIPOD) guidelines for reporting this study (**Supplemental Table S1**).

2.2. Participating patients

Eligible participants were all consecutive infants from 30 to 365 days old who underwent a first neuroimaging such as head CT or MRI between January 2015 and December 2017. Infants aged less than 30 days (born at term) or less than 30 days corrected age (born premature), with fever (temperature $\geq 38.3^{\circ}\text{C}$) during the 24 hours before admission were excluded, with neurological impairments (Glasgow Coma Scale < 13 or clinical description in case of unrated Glasgow Coma Scale), and/or with blood coagulation disorders (hemophilia, current anticoagulant therapy and/or cardiopulmonary bypass procedures < 1 month old, platelet count $< 100,000/\text{mm}^3$, and other documented coagulation abnormalities) were excluded. We also excluded infants with a reported history of

head trauma with severe mechanism of injury because the indication for performing neuroimaging was based on the head trauma clinical decision rules of Pediatric Emergency Care Applied Research Network in this specific setting. However, contrary to the first validation study [27], some included infants presented with a history of trivial head trauma notably if there was a discrepancy between the clinical presentation and the described severity of the trauma. Finally, we excluded infants with missing data such as indications for neuroimaging and criteria for the PIBIS CPR (clinical and dermatological examinations, head circumference and/or hemoglobin level).

2.3. Patient classification

Infants were classified according to the neuroimaging results (the gold standard test) as detailed in **Table 1**. As previously reported, infants who presented abnormal neuroimaging results with cephalic lesions, traumatic or non-traumatic, considered responsible for the symptomatology, were classified as cases [27]. Among them, infants presenting a traumatic cephalic lesion were considered to have potential AHT. The diagnosis of AHT was then stated as "certain" or "probable" by a multidisciplinary team specialized in child protection and following the recommendations of the French Health Authority [1]. All the children with suspected AHT underwent the recommended paraclinical examinations, to search for other lesions suggesting the inflicted trauma and possible differential diagnoses. In case of confirmed AHT diagnosis, neuroimaging results were proofread by an experienced pediatric radiologist. Infants with normal neuroimaging results or those with a cephalic or brain abnormality not responsible for any symptom (**Table 1**) were classified as controls. The neuroimaging results were interpreted either by the multidisciplinary team specializing in child protection or by the experienced pediatric radiologist, blind to the PIBIS rule result.

2.4. Data collection

Medical data were collected from medical records of infants. Demographic data, symptomatology, indications for neuroimaging, clinical (including head circumference) and dermatological examinations, neuroimaging and biological results (hemoglobin levels) were registered.

Table 1
Neuroimaging classification.

Neuroimaging classification	Description
Cephalic or brain lesion of probable traumatic origin	Subdural hematoma Extradural hematoma Subarachnoid hemorrhage Parenchymal hemorrhage (including petechial hemorrhage) Cerebral edema (without non-traumatic origin detectable) Skull fracture
Cephalic or brain abnormality of non-traumatic origin	Mass lesions (tumors, cavernoma, meningocele) Skull abnormality / defect (tumors, craniosynostosis) Hydrocephalus White matter abnormality Cortical dysplasia Arteriovenous malformation Ischemic or hemorrhagic stroke Encephalomalacia Significant unilateral extra-axial space, without recent bleeding, without clue for traumatic origin
Normal or clinically insignificant abnormality	No significant abnormality detectable Resolving cephalohematoma Benign extra-axial fluid of infancy Small cerebral cyst Sequelae of birth trauma or prematurity

2.5. PIBIS CPR

The PIBIS CPR was calculated, retrospectively, i.e. after the interpretation of the neuroimaging results, by using four objective criteria: suspicious dermatological abnormality (2 points), head circumference greater than the 85th percentile (1 point), serum hemoglobin level < 11.2 g/dl (1 point), and chronological age at neuroimaging \geq 3 months (1 point). The hemoglobin level was measured in a 7-day range around the neuroimaging date. Head circumference was measured up to 48 hours before neuroimaging. A positive score was defined as a PIBIS CPR \geq 2 points. Because it uses objective criteria, and the interpretation of the PIBIS rule result was not blinded to the neuroimaging results, the results cannot be affected by the non-blindness of gold standard results.

2.6. Statistical analysis

We described and compared the characteristics of cases and controls. Quantitative data are described with median and interquartile range (IQR) and categorical variables with number and percentage. We assessed the clinical performance of the PIBIS CPR in terms of sensitivity, specificity, and negative and positive predictive values and likelihood ratios with corresponding 95 % CIs by using the exact binomial method. We graphically represented the performance in terms of pre-test and post-test probabilities plotted in a Fagan nomogram. We then studied the frequency of infants diagnosed with ATH well identified or not by the PIBIS CPR. All analyses involved using R 3.4.2 (R Foundation for Statistical Computing, Vienna, Austria). $P < 0.05$ was considered statistically significant.

3. Results

3.1. Characteristics of participants

Of 443 eligible symptomatic infants from 30 to 365 days old who underwent a first neuroimaging, 129 were included: 33 (25.6 %) cases and 96 (74.4 %) controls. Symptoms presented by included patients are detailed in Table 2 and comprised discomfort, hematoma, vomiting, cardiac, tonic, and dermatological, eating or behavioral disorders. Overall, 33 (25.6 %) infants had abnormal neuroimaging results, with cephalic lesions, including 20 (60.6 %) with a confirmed AHT diagnosis (Fig. 1). For these 20 patients, traumatic cephalic lesions were diverse and/or multiple: 18 had a subdural hematoma, 7 subarachnoid hemorrhage, 4 skull fracture, 2 parenchymal hemorrhage, and 1 extradural hemorrhage. Thirteen patients (39.4 %) presented non-traumatic cephalic lesions: 4 hydrocephalus, 1 complex brain malformation, 1 stroke, 1 parenchymal non-traumatic bleeding, 3 mass lesion and 3 white or grey matter abnormality. Characteristics of cases and controls are in Table 2.

3.2. Clinical performance of PIBIS CPR

The mean (SD) PIBIS CPR for the 129 infants was 1.8 (1.3): 2.7 (1.4) for cases and 1.5 (1.1) for controls. The sensitivity and specificity of PIBIS CPR for identifying infants with abnormal neuroimaging results (traumatic or non-traumatic cephalic lesions) were 75.8 % ($n=25/33$) (95 % CI 57.7–88.9) and 61.4 % ($n=59/96$) (51.0–71.2). The pre-test probability of abnormal neuroimaging results with cephalic lesions was 25.6 % in this pediatric population. By applying the PIBIS score rule, the positive likelihood ratio (1.97, 1.43–2.70) and negative likelihood ratio (0.39, 95 % CI 0.21–0.74) yielded a positive post-test probability of disease (or PPV) of 40.3 % (95 % CI 28.1–53.6) and negative post-test probability (1-NPV) of 11.9 % (5.3–22.2) (Fig. 2).

3.3. Identification of AHT cases by the PIBIS CPR

Among the 20 infants with a diagnosis of AHT, 19 (95.0 %) were

Table 2

Characteristics of 129 infants included.

Mean (\pm SD) median (IQR) unless otherwise stated	Abnormal neuroimaging (n=33; 25.6 %)	Normal neuroimaging (n=96; 74.4 %)
Sex, girls, n (%)	12 (36.4 %)	35 (36.5 %)
Chronological age at neuroimaging (days)	154.0 (77.8)	147.0 (90.1)
	155.0 (93.0–211.0)	130.0 (61.0–208.8)
Hemoglobin level (gr/dL)	10.1 (1.5)	11.5 (1.1)
	10.1 (9.7–10.9)	11.5 (10.7–12.1)
Head circumference (cm)	43.3 (3.7)	41.1 (3.3)
	43.5 (41.0–45.8)	41.0 (38.5–43.5)
Age of onset of first symptoms (days)	133.5 (82.2)	126.4 (89.7)
	110.0 (70.0–194.5)	112.0 (53.3–179.5)
PIBIS CPR score	2.7 (1.4)	1.5 (1.1)
	2.0 (2.0–4.0)	1.0 (1.0–2.0)
Symptoms, n (%)		
Cardiac disorders	9 (27.3)	2 (2.1)
Tonicity disorders	17 (51.5)	33 (34.4)
Consciousness disorders	10 (30.3)	5 (5.2)
Behavioral disorders	14 (42.4)	29 (30.2)
Dermatological disorders	8 (24.2)	19 (19.8)
Eating disorders	8 (24.2)	22 (22.9)
Ophthalmic disorders	2 (6.1)	10 (10.4)
Respiratory disorders	0 (0.0)	2 (2.1)
Cephalohematoma	4 (12.1)	2 (2.1)
Vomiting	10 (30.3)	21 (21.9)
Discomfort	17 (51.5)	35 (36.5)
Seizure	6 (18.2)	21 (21.9)
Hematoma	10 (30.3)	19 (19.8)

CPR, clinical prediction rule; IQR, interquartile range; PIBIS, Pittsburgh Infant Brain Injury Score; SD, standard deviation.

correctly identified by the PIBIS CPR. Eight infants with abnormal neuroimaging results had a negative PIBIS CPR result and thus were not correctly identified. Among them, one had a diagnosis of AHT; the remaining 7 patients had non-traumatic cephalic lesions. The one infant with a diagnosis of AHT, 3.5 months old, was admitted to the ED for minor behavioral, and tonic disorders and vomiting, without a reported history of head trauma. In light of these multiple symptoms, head CT was rapidly performed and revealed a plurifocal subdural hematoma. Regardless, the hemoglobin level and head circumference were normal. Clinical examination did not reveal any dermatological abnormalities. Among the 7 infants with a diagnosis of non-traumatic cephalic lesions, 4 presented lesions that do not usually induce anemia or increased head circumference (white or grey matter anomaly, stroke, petechial parenchymal bleeding). Two presented a mass lesion and one had hydrocephalus.

4. Discussion

This study allowed for testing the PIBIS CPR in a French pediatric population admitted to the ED who underwent a neurological imaging. In our population, the sensitivity and specificity of the PIBIS CPR to detect infants with abnormal neuroimaging were 75.8 % and 61.4 %. The NPV and PPV for detecting abnormal neuroimaging results were 88.1 % and 40.3 %. Regarding AHT detection, among 20 infants with a diagnosis of AHT, 95 % were correctly identified by this rule. In the context of diagnosis difficulty, the PIBIS CPR seems not entirely accurate to help clinicians to select infants most likely to present brain injury, whose diagnosis would benefit from a head CT, and limit the delayed or missed diagnosis of AHT, a key point in abuse prognosis.

Regarding the prediction performance of the PIBIS CPR in detecting abnormal brain imaging results, the results from our study were lower than those from the original study [27] Although the specificity of PIBIS CPR was satisfying and similar to that from the original study (61.4 % [95 % CI 51.0–71.2] vs 53.0 % [95 % CI 49.0–57.0]), the sensitivity of the PIBIS CPR to detect abnormal neuroimaging results was lower in our

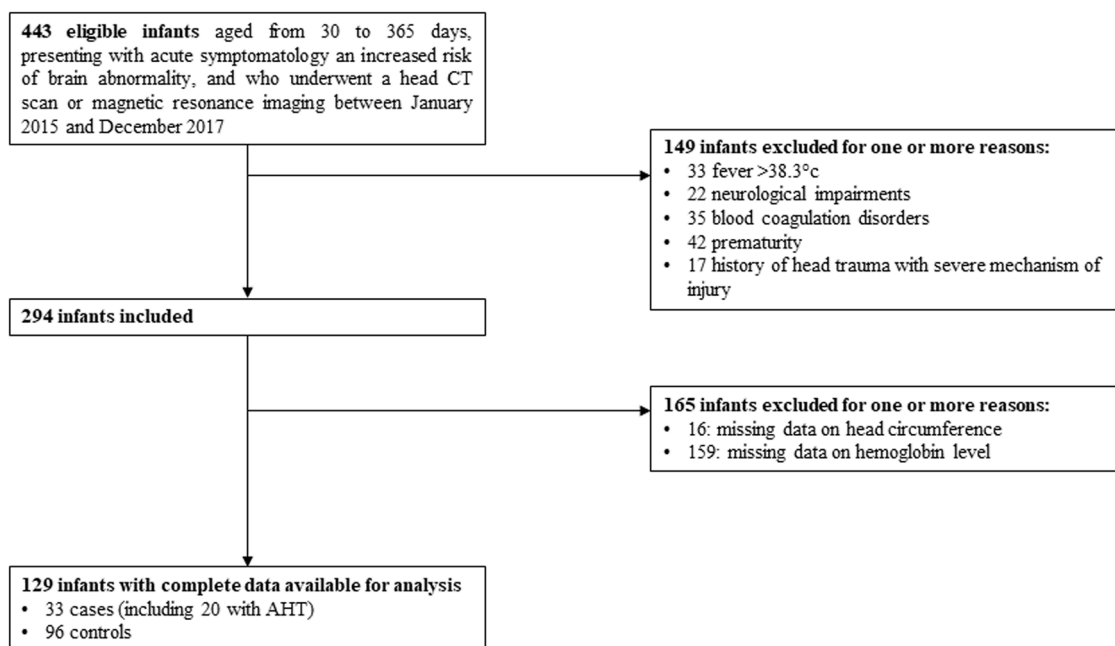


Fig. 1. Flow chart of participants.

AHT, abusive head trauma; CT, computed tomography.

study than the original study (75.8 % [95 % CI 57.7–88.9] vs 93.3 % [95 % CI 89.0–96.3]). This discrepancy in the predictive ability of the PIBIS CPR may be explained by differences between the validation populations [28,29]. All infants in our study underwent neuroimaging, whereas in the Berger et al. original study, a substantial number of infants (39 % of controls) did not undergo brain imaging. This situation could have led to a high bias in the Berger et al. classification because some missed AHT victims could have been considered as controls. Indeed, developmental, cognitive or behavioral consequences of AHT can appear very late (later than 6 months) [30,31], and furthermore around a quarter of the victims remain asymptomatic and have no visible sequelae [11,12]. This classification bias in the princeps study may also have affected the sensitivity value of the PIBIS CPR. Also, the prevalence of cerebral lesions was slightly higher in our study than in the original study (25.6 % vs 20.7 %) [27]. It should be noted that half of the eligible infants were excluded from this study due to missing data on either hemoglobin level or head circumference. These infants, who are likely to be less severe, would have had normal neuroimaging, leading to an underestimation of the specificity of PIBIS CPR in this study.

The PIBIS CPR was developed to maximize the detection of AHT in infants who appear well. This is the reason why patients who reported benign head trauma were not excluded from this study sample in contrast to the original study [27]. Indeed, several studies have well demonstrated that in a significant number of AHT cases, the caregiver of the child reported a history of accidental head trauma (often benign and incompatible with the severity of the lesions observed on brain imaging) [23,32–34]. Thus, we considered that this rule could be used in situations of reported benign head trauma also or in case of a dubious reported history. It should also be noted that only patients with a neuroimaging assessment were included in this study. This may have led to a selection bias since some patients with AHT should not have had neuroimaging [25,26]. Nevertheless, in our study, the NPV (88.1 %) and PPV (40.3 %) for detecting abnormal neuroimaging results were low and not appropriate for the clinician's concerns. Moreover, among 20 patients presenting AHT diagnosed by neuroimaging, one infant had a negative PIBIS CPR and would not have been identified to undergo neuroimaging based on this score alone. Therefore, we should remember that the PIBIS CPR remains an aid but not a substitute for clinical evaluation in the context of AHT. Clinicians should discuss

neuroimaging according to all the clinical signs of AHT and the medical history, even with a negative PIBIS CPR result. However, when an infant presents with mild neurological symptoms in pediatric EDs, the pediatricians must quickly decide whether or not to perform neuroimaging, taking into account the potential risks associated with sedation or radiation and the risk of missing a diagnosis of brain injury or AHT. In this context, the use of PIBIS CPR with a high NPV should help allow safe discharge without neuroimaging of children presenting with moderate symptoms.

Our findings require some improvements to the PIBIS CPR. Some criteria could be added, especially for detecting AHT. Indeed, relative macrocephaly defined by a head circumference abrupt increase instead of an absolute head circumference value (greater than the 85th percentile as proposed in the PIBIS CPR) could be added. As an example, in our study, the infant with AHT not identified by the PIBIS CPR alone had a normal head circumference, but the head circumference had abruptly increased at the time of the examination. Using criteria as continuous parameters instead of dichotomized variables could also allow for better clinical performance of the PIBIS CPR, as suggested by Berger et al [35]. Finally, several studies have suggested panels of serum biomarkers to detect intracranial lesions, with encouraging results [36].

Our study has a few limitations, including its retrospective design and some different inclusion criteria from the original study. Indeed, in addition to well-classified cases and controls, all infants included had undergone brain imaging, in contrast to the princeps study. This situation would have led to discrepancies in validation populations between the princeps study and our study, which could explain the observed differences in the clinical performance of the PIBIS CPR [27–29]. In addition, the limited number of cases and control in this study may have led to a lack of power.

5. Conclusion

Our external validation study showed the PIBIS CPR performed poorly in detecting infants with abnormal neuroimaging results as compared with the original study. This CPR could probably be refined by adding and/or modifying clinical and biological criteria and/or adding new biomarkers to be applied to our set of patients and to improve its clinical performance, particularly in the context of suspected AHT. A

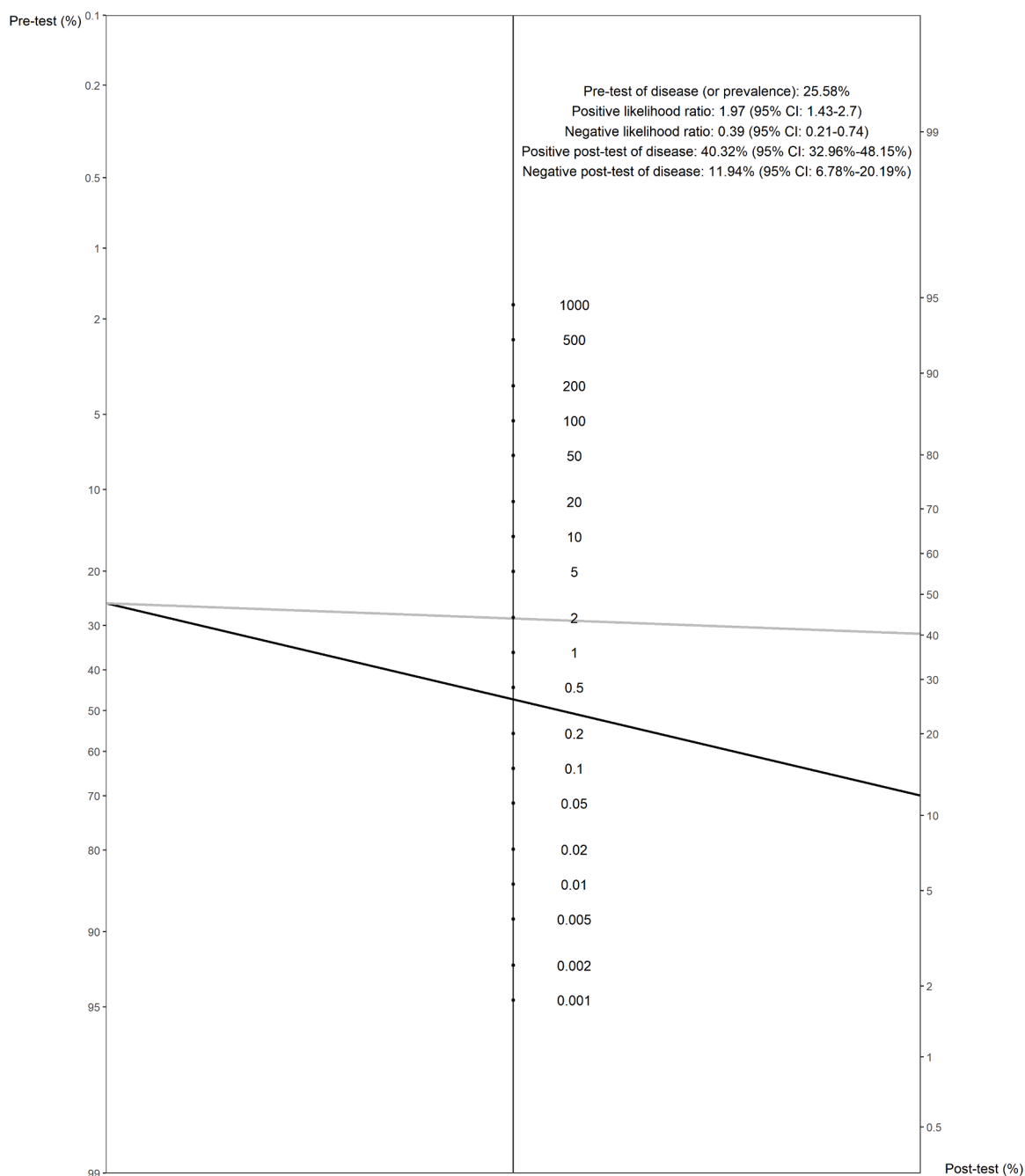


Fig. 2. Fagan nomogram of pre- and post-test probabilities with Pittsburgh Infant Brain Injury Score (PIBIS) clinical prediction rule (CPR). 95 % CI, 95 % confidence interval.

larger, prospective external validation study is needed to confirm these findings and to improve the clinical performance of the PIBIS CPR so as to help emergency clinicians with imaging prescription.

Availability of data and materials

The raw data can be obtained on request from the corresponding author.

Source of funding

None declared

Declaration of competing interest

All authors state no conflict of interest.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.arcped.2024.11.007](https://doi.org/10.1016/j.arcped.2024.11.007).

References

[1] Haute Autorité de santé. Syndrome du bébé secoué ou traumatisme crânien non accidentel par secouement. Recommandation de bonnes pratiques. Guide méthodologique Saint-Denis La Plaine: HAS. 2017. Available from: <https://www.hautsaute-sante.fr/fr/guide-recommandation-de-bonnes-pratiques/syndrome-du-bebe-secoue-ou-traumatisme-craniien-non-accidentel-par-secouement>.

- has-sante.fr/jcms/c_2794425/fr/syndrome-du-bebe-secoue-ou-traumatisme-cranien-non-accidental-par-secouement.
- [2] Adamsbaum C, Morel B, Ducot B, et al. Dating the abusive head trauma episode and perpetrator statements: key points for imaging. *Pediatr Radiol* 2014;44:578–88.
 - [3] Nadarasa J, Deck C, Meyer F, et al. Update on injury mechanisms in abusive head trauma—shaken baby syndrome. *Pediatr Radiol* 2014;44. Suppl 4:S565-70.
 - [4] Klevens J, Leeb RT. Child maltreatment fatalities in children under 5: findings from the National violence death reporting system. *Child Abuse Negl* 2010;34:262–6.
 - [5] Frasier LD. Abusive head trauma in infants and young children : a unique contributor to developmental disabilities. *Pediatr Clin North Am* 2008;55:1269–85.
 - [6] Parks SE, Kegler SR, Annett JL, et al. Characteristics of fatal abusive head trauma among children in the USA: 2003–2007: an application of the CDC operational case definition to national vital statistics data. *Inj Prev* 2012;18:193–9.
 - [7] Boop S, Axente M, Weatherford B, et al. Abusive head trauma: an epidemiological and cost analysis. *J Neurosurg Pediatr* 2016;18:542–9.
 - [8] Fanconi M, Lips U. Shaken baby syndrome in Switzerland: results of a prospective follow-up study, 2002–2007. *Eur J Pediatr* 2010;169:1023–8.
 - [9] Foerster BR, Petrou M, Lin D, et al. Neuroimaging evaluation of non-accidental head trauma with correlation to clinical outcomes: a review of 57 cases. *J Pediatr* 2009;154:573–7.
 - [10] Kesler H, Dias MS, Shaffer M, et al. Demographics of abusive head trauma in the commonwealth of pennsylvania. *J Neurosurg Pediatr* 2008;1:351–6.
 - [11] Barlow KM, Thomson E, Johnson D, et al. Late neurologic and cognitive sequelae of inflicted traumatic brain injury in infancy. *Pediatrics* 2005;116:e174–85.
 - [12] Lind K, Toure H, Brugel D, et al. Extended follow-up of neurological, cognitive, behavioral and academic outcomes after severe abusive head trauma. *Child Abuse Negl* 2016;51:358–67.
 - [13] Keenan HT. A population-based study of inflicted traumatic brain injury in young children. *JAMA* 2003;290:621.
 - [14] Barlow KM, Minns RA. Annual incidence of shaken impact syndrome in young children. *Lancet* 2000;356:1571–2.
 - [15] Shanahan ME, Zolotor AJ, Parrish JW, et al. National, regional, and state abusive head trauma: application of the CDC algorithm. *Pediatrics* 2013;132. e1546-e53.
 - [16] Niederkrötenhaler T, Xu L, Parks SE, et al. Descriptive factors of abusive head trauma in young children—United States, 2000–2009. *Child Abuse Negl* 2013;37:446–55.
 - [17] Keenan H, Runyan DK. Shaken baby syndrome. Lethal inflicted traumatic brain injury in young children. *N C Med J* 2001;62:340–3.
 - [18] Theodore AD. Epidemiologic features of the physical and sexual maltreatment of children in the carolinas. *Pediatrics* 2005;115. e331-e7.
 - [19] Theodore AD, Runyan DK. A survey of pediatricians' attitudes and experiences with court in cases of child maltreatment. *Child Abuse Negl* 2006;30:1353–63.
 - [20] Jenny C, Hymel KP, Ritzen A, et al. Analysis of missed cases of abusive head trauma. *JAMA* 1999;281:621–6.
 - [21] Letson MM, Cooper JN, Deans KJ, et al. Prior opportunities to identify abuse in children with abusive head trauma. *Child Abuse Negl* 2016;60:36–45.
 - [22] Oral R, Yagmur F, Nashelsky M, et al. Fatal abusive head trauma cases: consequence of medical staff missing milder forms of physical abuse. *Pediatr Emerg Care* 2008;24:816–21.
 - [23] Adamsbaum C, Grabar S, Mejean N, et al. Abusive head trauma: judicial admissions highlight violent and repetitive shaking. *Pediatrics* 2010;126:546–55.
 - [24] Duhaime A-C, Gennarelli TA, Thibault LE, et al. The shaken baby syndrome: a clinical, pathological, and biomechanical study. *J Neurosurg* 1987;66:409–15.
 - [25] Brenner DJ. Estimating cancer risks from pediatric CT: going from the qualitative to the quantitative. *Pediatr Radiol* 2002;32:228–31.
 - [26] Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. *Lancet* 2012;380:499–505.
 - [27] Berger RP, Fromkin J, Herman B, et al. Validation of the Pittsburgh Infant Brain Injury Score for abusive head trauma. *Pediatrics* 2016;138. e20153756-e.
 - [28] Leroy S, Bouissou F, Fernandez-Lopez A, et al. Prediction of high-grade vesicoureteral reflux after pediatric urinary tract infection: external validation study of procalcitonin-based decision rule. *PLoS One* 2011;6:e29556.
 - [29] McGinn TG, Guyatt GH, Wyer PC, et al. Users' guides to the medical literature: XXII: how to use articles about clinical decision rules. Evidence-Based Medicine Working Group. *JAMA* 2000;284:79–84.
 - [30] Bonnier C, Nassogne MC, Evrard P. Outcome and prognosis of whiplash shaken infant syndrome: late consequences after a symptom-free interval. *Dev Med Child Neurol* 1995;37:943–56.
 - [31] Laurent-Vannier A, Toure H, Vieux E, et al. Long-term outcome of the shaken baby syndrome and medicolegal consequences: a case report. *Am J Prev Med* 2009;52:436–47.
 - [32] Chadwick DL, Chin S, Salerno C, et al. Deaths from falls in children: how far is fatal? *J Trauma* 1991;31:1353–5.
 - [33] Ettaro L, Berger RP, Songer T. Abusive head trauma in young children: characteristics and medical charges in a hospitalized population. *Child Abuse Negl* 2004;28:1099–111.
 - [34] Reece RM, Sege R. Childhood head injuries: accidental or inflicted? *Arch Pediatr Adolesc Med* 2000;154:11–5.
 - [35] Royston P, Altman DG, Sauerbrei W. Dichotomizing continuous predictors in multiple regression: a bad idea. *Stat Med* 2006;25:127–41.
 - [36] Berger RP, Pak BJ, Kolesnikova MD, et al. Derivation and validation of a serum biomarker panel to identify infants with acute intracranial hemorrhage. *JAMA Pediatr* 2017;171:e170429.