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ORIGINAL ARTICLE

The role of retinal imaging in the management of abusive head trauma cases

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Abstract

Background As retinal hemorrhage (RH) is the most frequent and reliable finding of abusive head trauma (AHT), an ophthalmology consultation should be systematically required in suspected cases. Full retinal examination through pharmacologically dilated pupil can detect the type and pattern of RHs, helping to distinguish abusive from non-abusive head trauma.

Methods We performed a retrospective analysis of a case series of 6 infants (aged 0.6-10 months) with AHT who were admitted to the Emergency Department of Fondazione Policlinico Universitario A. Gemelli IRCCS in Rome with severe intracranial hemorrhages. Children underwent full multidisciplinary assessment including dilated fundus examination, optical coherence tomography (OCT) and digital wide-field fundus photography (DWFFP – in our case RetCam). In our paper we report the clinical presentation, the ocular findings and outcome at discharge.

Results The mean age at the hospital admission was 6.28 months. In all infants, intracranial hemorrhages were found. Preretinal and intraretinal hemorrhages were detected, collecting good-quality retinal images.

Conclusions Imaging of retinal hemorrhages represents a fundamental moment of AHT diagnosis and documentation. Although RetCam is the gold standard for the acquisition of retinal images in suspected cases, OCT is extremely valuable in forensic evaluation since it can detect even small macular hemorrhages. Therefore, the combination of RetCam and OCT imaging can give relevant hints for the diagnosis of AHT, allowing to evaluate the extent, spread and morphology of RHs.

Keywords Abusive head trauma · Retinal imaging · Optical coherence tomography · Wide-field fundus photography

Introduction

Abusive head trauma (AHT) —also known as "shaken baby syndrome"—is a form of child abuse in which the abuser inflicts a blunt trauma or vigorously shakes the infant or the toddler, typically to stop him from crying [1, 2]. In 1974 Caffey et al. [3] first described "Whiplash Shaken Infants Syndrome," characterized by intracranial and intraocular hemorrhages without signs of external trauma or skull fractures, associated with traction lesions of the long bones without fractures and traumatic changes in the overlying skin of the extremities and no history of trauma. The authors suggested to suspect this condition in all infants with unexplained seizures, forceful vomiting, bulging fontanel, or paralysis. Traditionally, AHT was defined by a diagnostic triad (subdural hematoma, retinal hemorrhage and encephalopathy), whose clinical significance has been recently reconsidered as these findings are not pathognomonic [4]. The annual incidence of AHT is 24.6/100,000 in children

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younger than 1 year [5] and of 12.8–17/100,000 in those younger than 2 years [6]. In 2015 Cowley et al. [6] tested a Prediction Tool for AHT based on six suggestive signs (i.e., retinal hemorrhages, rib and long-bone fractures, apnea, seizures, and head or neck bruising) characterized by a sensitivity of 72.3% and a specificity of 85.7%. This study reported that in children younger than 24 months, the probability of AHT was greater than 81.5% in the presence of three or more features. The lack of pathognomonic signs of AHT underlines the importance of defining clinical strategies to avoid missed diagnosis or misdiagnosis. Abuse detection allows to break the so-called cycle of abuse starting a judicial investigation [1] and to help the minor to overcome the traumatic events. Indeed, it was reported that abused children are exposed to an increased risk of developing physical/mental diseases and criminal behaviors with a tendency to perpetrate abuses in the adulthood [7].

Abuse should be considered by the physicians as differential diagnosis in cases of pediatric ocular trauma when suggestive signs of body and head injury (e.g., intracranial hemorrhage, unexplained loss of consciousness and seizures) are found at clinical examination. Levin and Christian [8] reported that from 4 to 6% of all abused children are recognized by an ophthalmologist. In particular, retinal hemorrhages (RHs)—both intraretinal and preretinal—represent the most common findings of abuse [9, 10]. Historically, indirect ophthalmoscopy was the first tool to diagnose retinal lesions. It is still widely used (mainly because of economic reasons), but it allows to examine only limited areas of the retina at once. Digital wide-field fundus photography was introduced more than two decades ago, has a relatively high economic cost, and is considered a reliable diagnostic tool because it is able to investigate the whole retina and to catch/store retinal images [11]. Another possible imaging tool is OCT, which is used to investigate the posterior pole and the optic nerve head, showing the different layers of the retina (and thus of the intraretinal hemorrhages) [12]. As RHs have few manifestations (i.e., visual impairment) and quickly disappear from retinal field [10], the American Academy of Pediatrics Council on Child Abuse and Neglect [13] recommends performing the ophthalmology consultation "preferably within the first 24 h and ideally within 72 h," with careful attention in presence of severe neurological sings at the admission to the emergency room [14]. Other rare ocular findings in AHT are retinoschisis, retinal folds, chorioretinal scars, and optic nerve sheath hemorrhages [15]. A detailed description of these ocular signs is needed to address the suspect towards AHT excluding alternative diagnoses. At the end of a full multidisciplinary examination, when there is a high suspicion of AHT, healthcare professionals are required to alert child protective service [14].

In this paper, we analyzed six cases of RHs in AHT evaluated by a team composed by an ophthalmologist, a pediatrician, and an expert in clinical forensic medicine. Our aim is to describe the informativeness of RetCam and OCT imaging in AHT cases, focusing on the possibility of evaluating the extent, the spread, and the morphology of hemorrhages.

Subjects and Methods

In this retrospective study, we reported the clinical presentation, ocular findings, and, when available, the outcome at discharge of six infants (mean age 6.28 months years; range 20 days–10 months) admitted to the Emergency Department of Fondazione Policlinico Universitario A. Gemelli IRCCS—from February 2015 to December 2019—with severe brain injury and/or physical injuries suggestive of abuse Table 1. At the admission, they underwent full clinical examination by a team composed by a pediatrician, a forensic expert, and an ophthalmologist. At the first clinical assessment, physicians ascertained cardiorespiratory arrest, status epilepticus, tonic-clonic seizures, severe intracranial hemorrhage, and stuporous state. Ophthalmologic examination was performed within 24 h. Portable slit lamp was used to explore the anterior segment of the eye and examine pupillary reflexes. Fundus was first examined without pupil dilation with a non-contact hand-held OCT (Bioptogen Leica). After that, in accordance with pediatricians, mydriasis was induced with Tropicamide 1% drops, and fundus was examined using indirect ophthalmoscope and wide field digital fundus camera (RetCam 3 Natus California) to document retinal findings.

Results

Case 1

A 5-month-old infant in cardiorespiratory arrest was brought to the emergency room. CT scan detected acute epidural hemorrhages in frontal regions, acute epidural-subarachnoid hemorrhage in left temporal region, acute subdural hemorrhage in right parietal region, and in the areas of cerebral falx and tentorium. At dilated fundus examination, bilateral, multiple and diffuse preretinal and intraretinal hemorrhages associated with hemovitreous were found (Fig. 1). After less than a day of hospitalization, the patient died.

Case 2

A comatose 8-month-old infant in status epilepticus was brought to the emergency room. CT scan showed acute subdural hemorrhage with signs of cerebral ischemia involving the right hemisphere and the left frontal lobe. At dilated

Table 1 Case series of children with AHT admitted to the Emergency Department of Fondazione Policlinico Universitario A. Gemelli IRCCS

	Age	Clinical presentation	CT scan findings	RetCam findings	OCT findings	Outcome
1	5 months	Cardiorespiratory arrest	Epidural hemorrhages in frontal regions, acute epidural-subarachnoid hemorrhage in left temporal region, acute subdural hemorrhage in right parietal region and in the areas of cerebral falx and tentorium	Bilateral, multiple and diffuse preretinal and intraretinal hemorrhages associated with hemovitreous	Optic nerve with normal morphology and depth. Posterior pole scan confirmed the presence of different layers of intraretinal hemorrhages	Hospitalization for half of a day and then died
2	8 months	Status epilepticus	Acute subdural hemorrhage with signs of cerebral ischemia involving the right hemisphere and the left frontal lobe	Both acute and chronic bilateral multiple retinal and preretinal hemorrhages	Optic nerve with normal morphology and depth. Posterior pole scan confirmed the presence of different levels of intraretinal hemorrhages	Coma
3	20 days	Tonic-clonic seizure	Subdural hemorrhages in the right fronto-parieto- temporal and in the left fronto-parieto-occipital region, and a diffuse subarachnoid hemorrhage	Several bilateral intraretinal hemorrhages in both the posterior poles and the mid-peripheral retinas	The OCT confirmed the presence of superficial layers of retinal hemorrhages	Neurologic sequelae
4	5 months	Stuporous state	Subarachnoid hemorrhage in frontal areas, along the cerebral falx and in tentorium region	Bilateral wide retinal and pre-retinal hemorrhages extended to the posterior pole and in the right eye an ischemic area surrounded by hemorrhagic spots	Optic nerve was blurred by large superficial hemorrhage. Examination of intraretinal layers in the large part of the posterior pole was not possible because of a vast preretinal hemorrhage	Neurologic sequelae
5	10 months	Stuporous state	A 6-mm-thick subdural hematoma in the right hemisphere associated with sub-arachnoid hemorrhage along the interhemispheric fissure	Bilateral diffuse preretinal and retinal hemorrhages and, in particular, a right massive preretinal hemorrhage extending from the optic papilla to the posterior pole	Lifting of the internal limiting membrane to the level of the serum-hemorrhagic exudate. Retinal thickening with a dark hemorrhagic area and its shadow in the underlying layers	Fully recovered from a neurological point of view
6	9 months	Tonic-clonic seizure	Subdural hematoma of the right hemisphere with a maximum thickness of 7 mm associated with a 3-mm-shift on the midline. A slightly displaced fracture in the left parieto-temporo-occipital area is documented	Both acute and chronic preretinal and retinal hemorrhages, extending to the posterior pole and the middle periphery of both eyes	Preretinal and intraretinal hemorrhages.	Coma

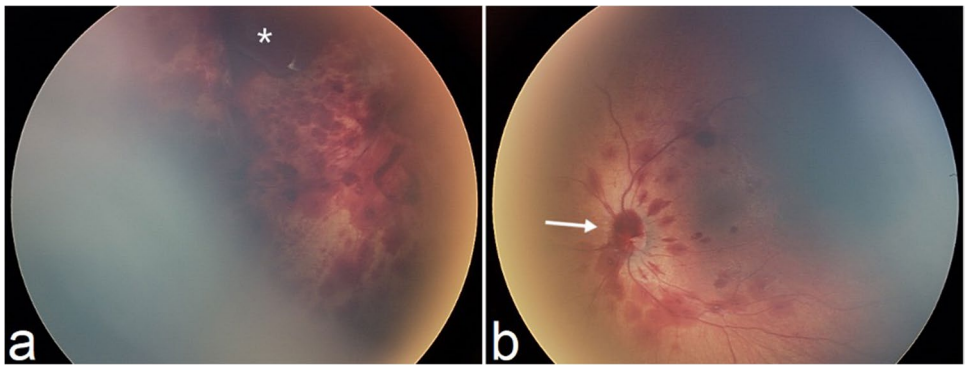

Fig. 1 Wide-field fundus photography of a patient with massive hemorrhage diffused in the posterior pole showing in **a** a blood collection (asterisk) and in **b** flame shaped and petechial hemorrhages starting from the optic disc (arrow), which follow the course of the retinal temporalis superior and inferior vascular arches

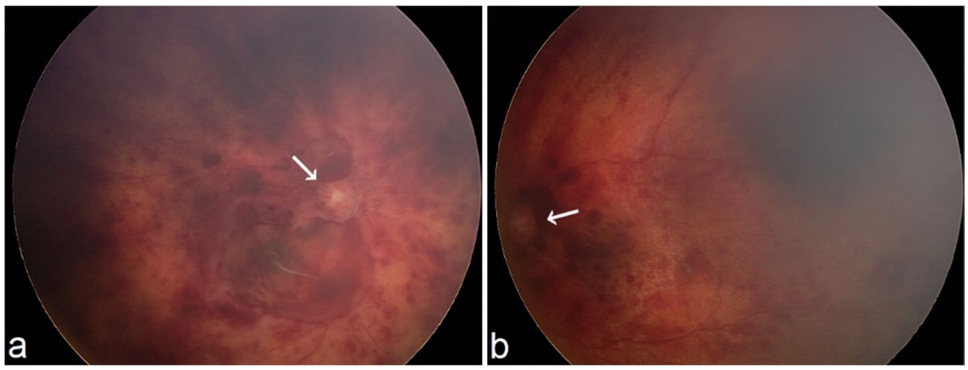

Fig. 2 **a, b** Wide-field fundus photographies showing a picture of massive hemorrhage, with pre-retinal fibrosis being organized in the posterior pole (arrows), due to fibrin deposition following the inflammatory action of extravasal blood

fundus examination, both acute and chronic bilateral multiple retinal and preretinal hemorrhages were found (Fig. 2). The patient was discharged in coma and never recovered.

Case 3

A 20-day-old infant was brought to the emergency room because of the sudden onset of tonic-clonic seizures. His mother reported that the newborn started experiencing breathing problems after an episode of regurgitation. Red bruises were found on the forehead, skin of the nose, and left periorbital area. In left submandibular region, a yellowish bruise was detected, while green bruises were present on the right cheek and the buttocks. CT scan revealed a diffuse subarachnoid hemorrhage and subdural hemorrhages in the right fronto-parieto-temporal and in the left fronto-parieto-occipital region. At dilated fundus examination, several bilateral intraretinal hemorrhages in both the posterior poles and the mid-peripheral retinas were found (Fig. 3). After a month of hospitalization, he was discharged with neurologic sequelae.

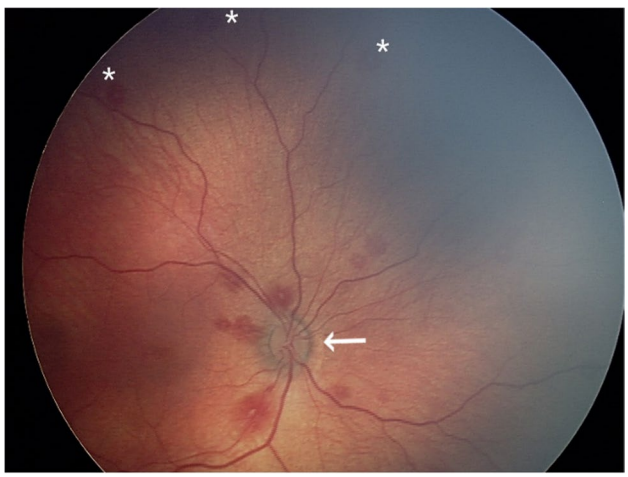

Fig. 3 Wide-field fundus photography showing organized hemorrhages around the optic disc (arrow) along the course of the retinal vessels. There are also small hemorrhages in the mid-periphery (asterisks)

Case 4

A 5-month-old infant in stuporous state was brought to the emergency room. His father reported that he fell off the crib. Two red large bruises were found on the torso and on the right arm. CT scan showed subarachnoid hemorrhage in frontal areas, along the cerebral falx and in tentorium region. At dilated fundus examination, bilateral wide retinal and pre-retinal hemorrhages extended to the posterior pole and in the right eye an ischemic area surrounded by hemorrhagic spots were found (Fig. 4). After a month of hospitalization, he was discharged with neurologic sequelae.

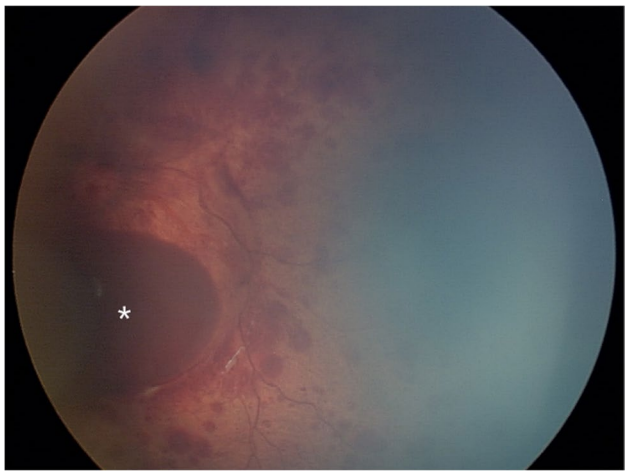

Fig. 4 Wide-field fundus photography showing a voluminous intraretinal blood collection in the posterior pole (asterisk) with numerous hemorrhages spread along the vascular arches and in the mid-periphery

Case 5

A 10-month-old infant in stuporous state was brought to the emergency room. Several bruises were found on the face and on the back. CT scan detected a 6-mm-thick subdural hematoma in the right hemisphere associated with sub-arachnoid hemorrhage along the interhemispheric fissure. At dilated fundus examination, bilateral diffuse preretinal and retinal hemorrhages, and, in particular, a right massive preretinal hemorrhage extending from the optic papilla to the posterior pole were found (Figs. 5 and 6). After a month of hospitalization, the patient fully recovered from a neurological point of view.

Case 6

A 9-month-old infant was brought to the emergency room because of the onset of tonic-clonic seizures. CT scan showed a subdural hematoma of the right hemisphere with a maximum thickness of 7 mm associated with a 3-mm-shift on the midline. Imaging also detected a slightly displaced fracture in the left parieto-temporo-occipital area. At dilated fundus examination, a lot of acute and chronic preretinal

Fig. 5 Fundus photos of a retinal hemorrhage evolving over time (arrows). In **a**, an intraretinal hemorrhagic sac is indicated that affects the macular area and extends to the papillary area. In **b**, the same hemorrhage is shown in the partial resorption phase. In c there is complete resorption with clearing of the vitreous

Fig. 6 OCT of the same patient showing the morphology of the retina with hemorrhage (single arrows) on three different levels of the macular area (colored lines in **a**). In **b**, the lifting of the internal limiting membrane to the level of the serum-hemorrhagic exudate is shown. In **c**, the retinal thickening with a dark hemorrhagic area and its shadow in the underlying layers (double arrow).

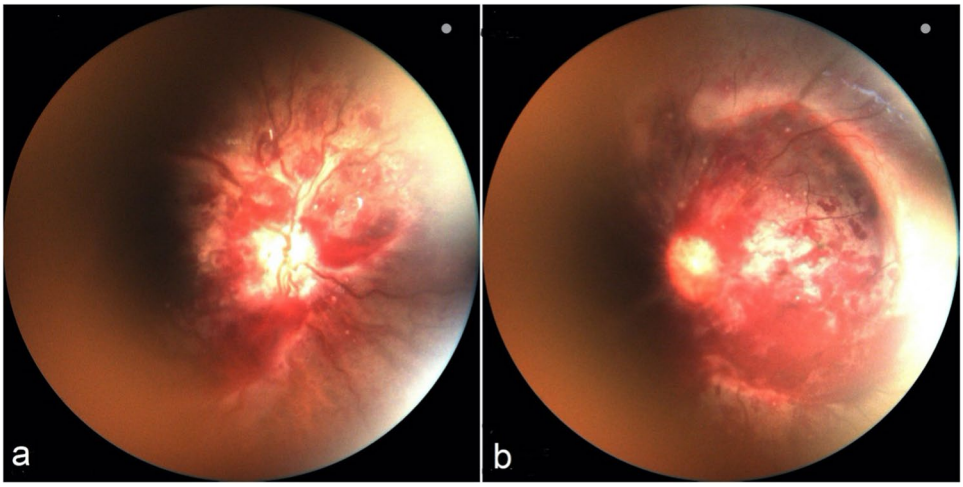

Fig. 7 Fundus photographs showing diffuse haemorrhages to the posterior pole of both the right eye (**a**) and the left eye (**b**)

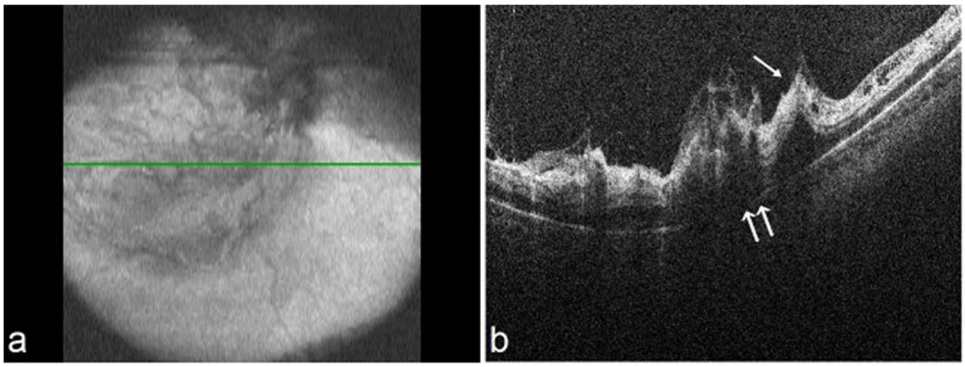

Fig. 8 OCT of the same patient showing retinal changes due to preretinal and intraretinal haemorrhages. In **a** is shown the fundus section that was scanned. In **b** it is possible to observe both preretinal haemorrhage (single arrow) and intraretinal serum collection (double arrow)

and retinal hemorrhages extending to the posterior pole and middle periphery of both eyes were found (Figs. 7 and 8). The patient was discharged in coma and never recovered.

Discussion

RetCam

RetCam (Pleasanton, CA, USA) is a digital wide-field fundus imaging system; it is the gold standard for imaging documentation, recording the combined appearance of both eyes by capturing a 130-degree field with 10-12 montaged retinal images. This portable device is used to capture retinal images in infants—lying in supine position—that are suspected for AHT [16]. The utility of RetCam for AHT is usually studied on sedated or ventilated infants. In clinical practice, sedation may be required if retinal angiography is needed [17]. In a retrospective case series of 10 eyes of 5 pediatric patients with a history of AHT, Tran et al. [18] reported that fluorescein angiography (FA) was found to have a distinct advantage in cases with late presentation to the clinical assessment. In addition, preretinal and/or vitreous hemorrhages may be related to the development of retinal non-perfusion which can be detected easily by FA. Therefore, when AHT is suspected, FA should be recommended [19].

OCT

Compared to RetCam, OCT imaging can provide additional information about the eye anatomy, improving the detection of infants with AHT [20]. Hand-held OCT reveals preretinal blood accumulation followed by vitreous detachment or retraction as well as persistent attachment of the vitreous to the internal limiting membrane as a sign of small macular hemorrhage. Also, the vitreoretinal membrane may be seen in OCT, supporting the mechanism of direct mechanical trauma [21].

Retinal hemorrhages and abusive head trauma

RHs are relatively frequent injuries, accounting for 15.1% of all admissions to pediatric emergency intensive care unit [22]. Although RHs can be a common finding also in non-abused children, the association with AHT is very strong

with a sensitivity of 75% and a specificity of 94% [15]. In their retrospective study, Binenbaum et al. [9], reported that the odds ratio in children younger than 6 months of age between RH and abuse was 11.7, underling that RH severity correlated positively with abuse on respect with accident. Moreover, the significant correlation between the severity of RH and the severity of neurological injury has been reported [23]. An accurate report of RHs during ophthalmological examination is therefore critical. The introduction of digital wide-field hand-held fundus photography (DWFFP) (pioneered by the RetCam system -actually RetCam III Natus, California USA) became the basis for innovative standard approach to retinal imaging in AHT, improving the management and the diagnosis of abuse [16]. Compared to ophthalmoscopy, DWFFP has a better sensitivity (100%) and specificity (85.7%) providing accurate documentation in suspected cases of AHT [24]. In our series, RetCam showed a 100% sensitivity and specificity in the detection of RHs.

Many authors proposed a grading system to describe RHs in AHT for medicolegal, clinical, and research purposes [25–27]. These authors adapted the classification introduced by the International Classification of Retinopathy of Prematurity (ROP) [28] and proposed "zonal" criteria—diving posterior pole to the periphery—including the extent, spread, and morphology of RHs. In 2014 Bhardwaj et al. [29] developed the traumatic hemorrhagic retinopathy (THR) grading system for evaluating and quantitatively analyzing retinal findings in AHT. This score was based on three "grades" for extension (Grade 1: region 1 only involved; Grade 2: region 2 involvement with or without region 1; Grade 3: retinoschisis or retinal fold); three "subgrade" for spread (A Mild 10 or fewer RH; B, moderate more than 10 but less than 50% of the retina involved; C, severe more than 50% of the retina involved); and two "sub-subgrades" based on RH morphology (i: intraretinal hemorrhages excluding sub-inner limiting membrane; ii: all extraretinal hemorrhages including vitreal). At the end of the examination, the observed ocular lesions can easily be converted in an ordinal variable from 0 to 18 for statistical analysis. Applied on DWFFP, this rating system showed a good intra-interobserver agreement.

Limitations and perspectives of current techniques for fundus examination

Despite—as said—DWFFP represents the gold standard for retinal imaging documentation, it has some limitations of application to clinical practice: it is a contact system, not well tolerated by an awake infant, with also the risk of eliciting the oculo-cardiac reflex because of the significant pressure applied on the eyeball to obtain good-quality images. Moreover, as this technique requires an annular light source, the imaging quality is highly affected by pupil size. Therefore, peripheral retina visualization, a key-issue in the diagnosis of AHT [30], is often difficult to evaluate despite 130° field of view claimed by manufacturer. In these cases, the use of fluorescein angiography (FA) in combination with DWFFP is known to improve peripheral retina vascular network visualization [31]. In a long-term follow-up of children with AHT, wide-field FA revealed peripheral retinal ischemia of uncertain origin [19, 32, 33]. However, we must point out that performing a FA in an emergency room is logistically difficult. In 2017 Yusuf at al. [34] proposed the use of a non-contact ultra-widefield 200° retinal imaging (Optos P200MA) on 10 infants with AHT lying on the so-called "flying baby position" (characterized by the infant's trunk supported by the forearm, chin supported by the hand, with the contralateral hand placed on the occiput for stability) and avoiding intubation at the intensive care unit. This device provides high-quality images and can be associated with FA (if necessary). However, Optos is not portable and its accessibility and comfortability are limited. Despite this, it has the advantage to detect the complications of AHT, including macular schisis and pre-macular hemorrhage. Regardless of this attempt to standardize the clinical assessment and the systems/methods of evaluation of the ocular findings, multiple studies have reported persisting disparity and bias in physicians' decisions to evaluate, diagnose, and/or report RHs in suspected child abuse [35]. This critical issue underlines the importance of finding an imaging system which can provide an objective and quantitative evaluation of retinal findings in AHT suspected cases.

Limitations of RetCam can be partially overcome combining, as showed by our cases, this technique and OCT. Indeed, OCT is technically easier, safer, and less invasive than wide-field contact portable fundus camera, providing additional information in infants with AHT [21]. Moreover, in 2020, Rufai et al. reported that in children, OCT imaging can predict the future visual acuity [36]. Therefore, OCT, used during the follow-up and for the personalized neuro-visual rehabilitation programs of children with AHT, has both a diagnostic and prognostic value.

In conclusion, as showed by our cases, the combination of RetCam and OCT imaging can give relevant hints for the diagnosis of AHT, allowing to evaluate the extent, spread, and morphology of hemorrhages.

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Availability of data and material Data are available on reasonable request to the corresponding author

Declarations

Ethics approval, Consent to participate, Consent for publication the study complies with the principles of Helsinki Declaration and with the requirements of European Union GDPR regarding consent.

Conflict of interest The authors declare no competing interests.

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