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The Medicolegal use of Neuroimaging in Term Neonatal Hypoxic Ischemic Encephalopathy

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Abstract

Neonatal hypoxic ischemic encephalopathy (HIE) is a common source of malpractice lawsuits. The consequences of HIE can be severe and lifelong, creating large financial tolls for patients and their families. Even when malpractice cases are seemingly baseless, they can often be brought against obstetricians in hopes of offsetting medical expenses. In such cases the timing of the injury becomes paramount, specifically whether the injury occurred in utero or intrapartum. When applied appropriately, medical imaging can provide valuable objective data and insight into the timing of the injury and thus becomes a vital tool for shedding light on what is often a murky and ambiguous topic in HIE lawsuits. However, it may not be known that delaying imaging past a certain point can severely limit the ability to time injuries and differentiate between those that occurred in utero as opposed to intrapartum. This manuscript offers recommendations for when to perform imaging in order to maximize the ability to time those injuries that lead to HIE. Specifically, we advise that providers obtain a neonatal brain ultrasound within one day of birth and brain magnetic resonance imaging (MRI) between 24 hours and six days of birth in cases of suspected HIE in term neonates. It is important to note that our suggestions should not supersede any individual patient circumstances, and that patient treatment plans should be formulated by their care teams (including obstetricians and pediatricians), taking all factors into account.

Keywords: Hypoxic Ischemic Encephalopathy; Ultrasound; MRI; Lawsuit; Cerebral Palsy

List of Abbreviations

HIE: Hypoxic ischemic encephalopathy; CP: Cerebral Palsy; ACOG: American College of Obstetricians and Gynecologists; MRI: Magnetic Resonance Imaging; DWI: Diffusion-Weighted Imaging; ADC: Apparent Diffusion Coefficient; TH: therapeutic hypothermia

Introduction

Hypoxic ischemic encephalopathy (HIE) is one of the most serious perinatal brain injuries. Perinatal asphyxia has been reported in as many as one to six out of every one thousand live term births, with roughly half of these cases causing ischemic encephalopathy and up to 20% resulting in death [1-3]. Consequences of HIE in survivors can be lifelong, manifesting most commonly as cerebral palsy (CP) but also as epilepsy as well as intellectual and other motor disabilities [4-8]. In addition to the physical and emotional damage there is a lasting financial toll that patients and their families must endure. The CDC estimates an average increased lifetime cost of $921,000 per CP patient [9]. As such, even when malpractice lawsuits are seemingly baseless, they can often be brought against healthcare professionals in hopes of offsetting current and future medical expenses [10]. Most cases carry an average indemnity of $524,000 (although some cases result in multimillion dollar awards), making birth injuries one of the most costly medical malpractice claims to date [11].

Risk factors for HIE can be antepartum (such as genetic abnormalities, environmental and sociodemographic factors), or they may be associated with birth (such as shoulder dystocia, chorioamnionitis, or uteroplacental insufficiency such as in cases of abruptio placenta or rarely maternal hypoxia). Any one or combination of these may lead to HIE [12]. Clinically, an executive summary created by a joint taskforce between the American College of Obstetricians and Gynecologists (ACOG) and the American Academy of Pediatrics describes the following criteria for attributing HIE to intrapartum events: (1) Apgar score of <5 at 5 minutes and 10 minutes of life, (2) fetal acidemia (pH <7.0 or base deficit ≥ 12 mmol/L), (3) brain magnetic resonance imaging (MRI) with evidence of acute brain injury, and (4) hypoxic-ischemic encephalopathy multisystem organ failure [12].

Previously, the Vermont Oxford Network Neonatal Encephalopathy Registry showed that only one-third of neonates diagnosed with encephalopathy have MRIs performed and 15% of all neonates had no imaging performed [13]. Historically, MRIs have defined most cerebral injuries as acute, contradicting epidemiologic studies that time most injuries to be chronic and remote from delivery [14,15]. Recent studies have highlighted the importance of appropriately timed imaging to delineate acute from chronic injury. The purpose of this article is to provide helpful imaging guidelines to health care teams (mainly obstetricians) facing the difficult situation of a patient with suspected HIE. Importantly, the imaging recommendations within this paper are not meant as replacements for those recommendations offered by other professional societies, but rather as suggestions based on the authors' years of medicolegal experience and supported by the literature.

An Overview of the Legal Process and Expert Testimony

The fundamental basis of a neonatal HIE lawsuit is the claim that a physician failed to adhere to the standard of care during the birth, leading to intrapartum asphyxia and causing HIE [16]. Expert witnesses are often called from various specialties to offer their professional opinions and provide testimony on behalf of either the party filing the suit, the plaintiff, or the physician being sued, the defendant. Oftentimes, a critical aspect of the counterargument is that the injury occurred in the antepartum period, rather than being caused by intrapartum factors (Figure 1). As such, accurate timing of the injury becomes paramount [16].

Multiple methods have been employed to help estimate the time of the initial injury, including pathologic analysis of placental tissue or autopsy evaluation of those neonates who sadly do not survive. Radiology offers a noninvasive or minimally invasive means of helping to accurately estimate the time of ischemic injury, with ultrasound and MRI being the best imaging modalities to determine the timing of the injury. In doing so, it can provide information that is critical in the setting of a malpractice suit. Specifically, we advise that healthcare providers obtain a neonatal brain ultrasound within one day of birth and a brain MRI between 24 hours and six days

of birth in cases of suspected neonatal HIE (Figure 2).

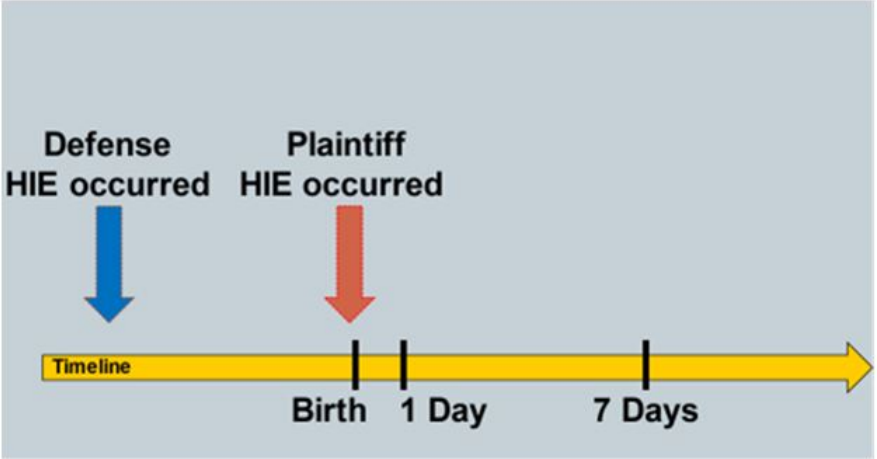


Figure 1: The medicolegal battle with regard to timing of neonatal injury. A visual diagram illustrates the timeline of an infant's birth and the proposed time of the hypoxic-ischemic encephalopathy according to both the defense (blue arrow) and the plaintiff (red arrow). HIE: Hypoxic ischemic encephalopathy. MRI: Magnetic resonance imaging. US: Ultrasound.

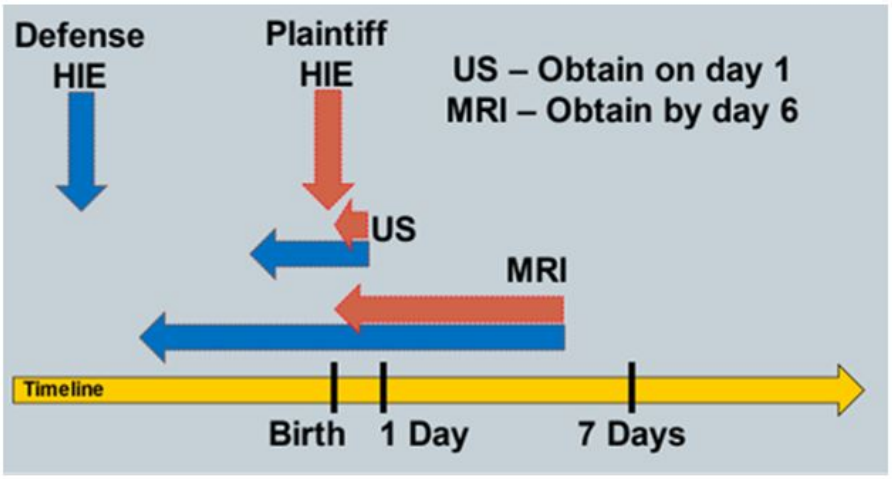


Figure 2: Optimal timing of neonatal neuroimaging to identify the onset of ischemic injury. An ultrasound is most accurate when performed on day 1 of life and MRI is most accurate if performed on or before day 6 of life. Neuroimaging performed at this time can help determine if the injury occurred antepartum prior to birth, which is the argument of the Defense (blue arrow). HIE: Hypoxic ischemic encephalopathy. MRI: Magnetic resonance imaging. US: Ultrasound.

Neonatal ultrasounds obtained after 24 hours and brain MRIs obtained after six days of birth are less likely to help date the initial injury (Figure 3), as positive findings seen on either exam during this time frame may stem from injuries that occurred either prior to labor, during the birthing process, or even after birth, and are thus less helpful when investigating for a source of injury as well as in the setting of malpractice suits. The rationale behind this is discussed fully in the following sections. It is important to note that these examinations should be conducted by providers experienced in neonatal imaging, and that interpretation should be performed by radiologists with experience in the field.

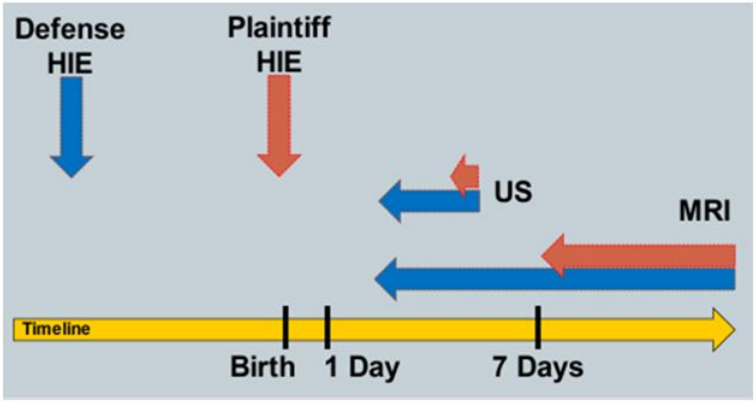


Figure 3: Impact of delayed neuroimaging on identifying the timeline of ischemic injury. Ultrasound performed after day 1 of life or MRI performed after 6 days of life are less likely to be helpful in determining the timing of injury, as positive findings on such studies cannot reliably differentiate antepartum from intrapartum injury. HIE: Hypoxic ischemic encephalopathy. MRI: Magnetic resonance imaging. US: Ultrasound.

Clinical Presentation of Hypoxic-Ischemic Encephalopathy

In response to a prolonged or sudden lack of oxygen, the neonatal brain switches from aerobic to anaerobic metabolism, causing a rapid depletion of ATP stores and buildup of lactic acid. This results in a cascade of toxic processes that lead to brain cell death via apoptosis and necrosis [7,17]. Neonatal encephalopathy may be apparent in neonates born in the 35th week or later within the first few hours of life. Before five years of age, some, but not all, of these infants will be diagnosed with cerebral palsy (especially spastic or dyskinetic quadriplegia) [12]. While the rate of cerebral palsy decreases with increasing gestational age, 60% of cases with cerebral palsy occur in children born in the late preterm period or after a term delivery [18].

Using Imaging Findings to Date Hypoxic-Ischemic Encephalopathy

Ultrasound

Ultrasound is often the initial imaging study in such cases due to its portability, low cost, and easy repeatability [19-21]. These advantages make it the practical first-line imaging study for fragile neonates with HIE being monitored under strict conditions in neonatal intensive care units. While there are some disadvantages to ultrasound, specifically that it is a modality heavily influenced by operator experience, its main advantage is that it is readily available in the NICU and does not require transportation of a potentially sick neonate, as is often required by other imaging modalities such as MRI.

Physiologically, regions of the brain affected by HIE become inflamed and edematous. This cerebral edema is what can ultimately be seen as a brighter hyperechoic signal with poorly defined borders on ultrasound, often involving the basal ganglia and thalami (Figure 4B) [22]. As time passes and these regions of ischemia mature, the hyperechoic signal becomes more apparent. Developing edema will often efface the cortical sulci and increase pressure on the ventricles, causing them to take on a slit-like appearance (although notably, the ventricles can appear small in the first 36 hours after birth in healthy neonates (Figure 4A)) [22]. However, as cerebral edema is often slow to develop and mild in the initial stages of injury, this hyperechoic signal is often not apparent until 24-48 hours after injury. Although there is some variability depending on injury severity and other patient factors, multiple sources note that ultrasounds in HIE patients obtained prior to 24-48 hours lack sensitivity and often demonstrate normal signal with no visible evidence of injury [19,22-25]. Some studies have even extended this time frame, suggesting that it may take up to 72 hours for findings of HIE to become apparent on ultrasound [24]. The rarity of visible edema on ultrasound prior to 24 hours makes ascertaining exact percentages difficult.

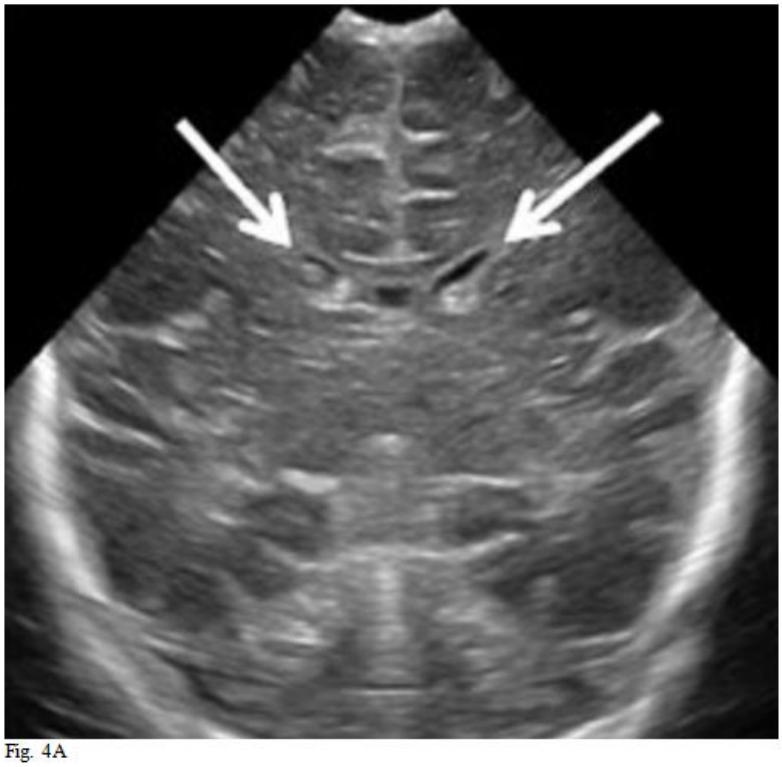


Fig. 4A

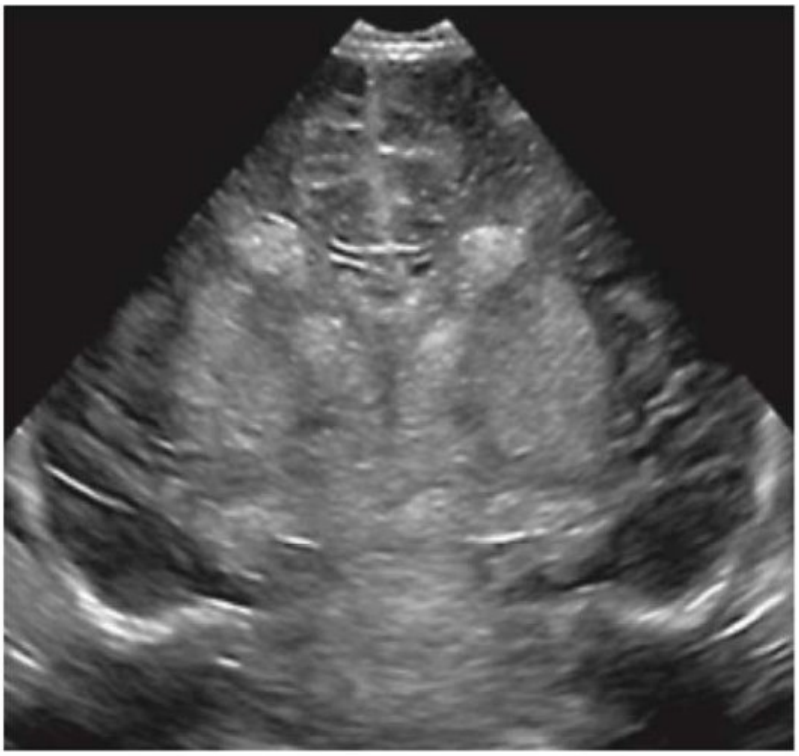


Fig. 4B

Figure 4: A. Normal neonatal ultrasound demonstrating normal echogenicity of the brain parenchyma. White arrows indicate normal configuration of the bodies of the lateral ventricles, which may appear somewhat small on initial head ultrasound in healthy term neonates. B. Increased echogenicity in the bilateral basal ganglia and thalami corresponding to ischemia in a severe profound pattern of injury. The ventricles are slit-like in this patient, secondary to increased edema from the central structures. Neonatology. 2018;114(3):185-197, reprinted with permission [22].

This delay between the injury itself and the ability to detect cerebral edema on ultrasound is one means by which providers can attempt to estimate the time of the injury. For instance, edema seen on a neonatal ultrasound obtained within one day of birth implies that the injury occurred at least 24-48 hours prior, in other words antepartum. Conversely, ultrasound studies obtained later than 24 hours after birth are less helpful in estimating the time since the initial injury, as they usually cannot reliably differentiate between those injuries that occurred antepartum and those that occurred during labor and delivery. **We recommend that health care teams attempt to obtain an initial neonatal intracranial ultrasound within 24 hours of birth in cases of suspected HIE, as this offers the greatest chance that imaging can help time the injury relative to birth.** Positive findings on an ultrasound obtained within the first 24 hours of life after birth suggest that the inciting injury occurred in utero, rather than during the birthing process itself. As noted previously, the authors' suggestion that ultrasound be obtained within the first 24 hours after birth should not supersede any individual patient circumstances. It is also important to note that other pathologies (such as hypoglycemia) [22] can demonstrate similar increased signal on ultrasound, and that ultrasound findings should ideally be evaluated in conjunction with subsequent MRI findings to form a final conclusion.

MRI

As noted previously, ultrasound has become the first-line imaging of choice given its ease of use, portability, and the ability to readily repeat studies when necessary. However despite its convenience, ultrasound is limited by multiple factors, including inter-operator variability and a lower sensitivity for subtle findings of HIE [7,26]. MRI is the most sensitive imaging modality for evaluating HIE and is considered the gold standard in this setting [2,19,21,27]. Given MRI's high sensitivity, it may even be possible to in retrospect find evidence of HIE on prior ultrasounds that were initially interpreted as normal, should a subsequent MRI demonstrate findings of HIE. However, many providers choose to delay MRI, perhaps due to difficulties coordinating imaging with ongoing treatment or a hesitancy to transport fragile neonates out of the strictly controlled environment of the NICU. Although several institutions have recently begun testing using portable MRI devices in NICU centers, the practice has yet to become widespread [19]. While MRI studies ordered after the first six days are still helpful in determining patient prognosis, it may not be known that such a delay can severely limit the ability to time the initial injury relative to birth. This factor should be weighed against other concerns.

Among those sequences included in a general MRI, conventional T1 and T2 imaging and diffusion-weighted imaging (DWI) are the most helpful for timing the initial injury. Data in T1 and T2 weighted MRI sequences is obtained by aligning hydrogen protons along a strong external magnetic field and then knocking them out of alignment with a radiofrequency pulse. By measuring the time needed for protons to realign along the magnetic field, radiologists can differentiate different substances within the body (i.e. blood, fat, fluid, muscle), which align at different rates. In cases of HIE, affected grey matter generally takes on an abnormally hyperintense T1 signal. The cause of this may be due to microhemorrhage (blood generally appears hyperintense on T1 imaging). However, other suggested etiologies include lipid release from myelin breakdown, neuronal mineralization, or even a paramagnetic effect of free radicals [7,20]. T2 signal usually initially presents as hypointense signal, later transitioning to a hyperintense signal over several weeks [12]. In general, positive findings on T1 and T2 weighted MRI sequences can be seen approximately 2-3 days after injury. They can potentially remain positive for months (although this may vary by individual based on levels of unmyelinated brain) [7,26,28].

Diffusion-weighted imaging, the MRI sequence most frequently used to diagnose acute brain infarcts, analyzes the random Brownian motion of water molecules inside brain tissue to identify regions of restricted diffusion, where water molecules are unable to diffuse freely [29]. This is useful in the setting of ischemic brain injury, where oxidative stress causes mitochondrial dysfunction and disrupts the balance of ions across the cell membrane. This causes water to flow into damaged brain cells along with an inability of these cells to expel excess water and sodium into the extracellular space, ultimately leading to cellular swelling and brain edema [29-31]. Thus the passive diffusion of water molecules becomes re-

stricted as water becomes trapped within damaged brain cells [29]. By using DWI sequences to detect these areas of restricted diffusion, radiologists can map areas of ischemic injury in the brain.

Regions of restricted diffusion appear hyperintense on DWI MRI sequences and hypointense on companion Apparent Diffusion Coefficient (ADC) sequences (Figure 5). These changes can often be detected within the first day of HIE, even as early as 20 minutes [32], as cellular functions are disrupted [1,26,27,33,34]. However, such findings can initially be extremely subtle and not demonstrate the full extent of injury, to the point that there is a slight chance that DWI in HIE patients obtained within the first 24 hours of injury can appear falsely normal [7,26,35,36]. After 24 hours, these findings continue to evolve, and the brightness of diffusion-weighted imaging increases, becoming most apparent 2-5 days after injury [7,12,22,26,28,34,36]. Subsequently, positive DWI findings begin to resolve in a process known as pseudonormalization, thought to result from breakdown of damaged cell walls, allowing water to diffuse back into the extracellular space [37]. It is important to note that while findings on DWI may improve, this does not indicate improvement or resolution of the underlying injury [7]. Although there is some variation, pseudonormalization is usually observed in HIE approximately 7-10 days after the initial injury. Studies often note a return to relatively normal DWI findings towards the end of the first week [7,12,23,26,36,37] In neonates undergoing therapeutic hypothermia (TH) for treatment of HIE, pseudonormalization can be seen at the later end of this range (i.e. 8-10 days) [22,33,] with one study noting pseudonormalization as late as 11-12 days after injury in patients treated with TH [33]. It is helpful to note that while the timing of pseudonormalization may be influenced by therapeutic hypothermia, the prediction of overall prognosis does not appear to be affected [8,38].

The observation that pseudonormalization occurs approximately 7-10 days after injury (and even later, in some cases of patients undergoing therapeutic hypothermia) offers another valuable tool for estimating the timing of injury. For instance, if an MRI of a patient with clinical HIE obtained four days after birth shows pseudonormalization (increased T1 signal out of proportion to resolving DWI signal), this strongly suggests that the injury occurred at least seven days prior to the study, and thus prior to birth (Figure 6).

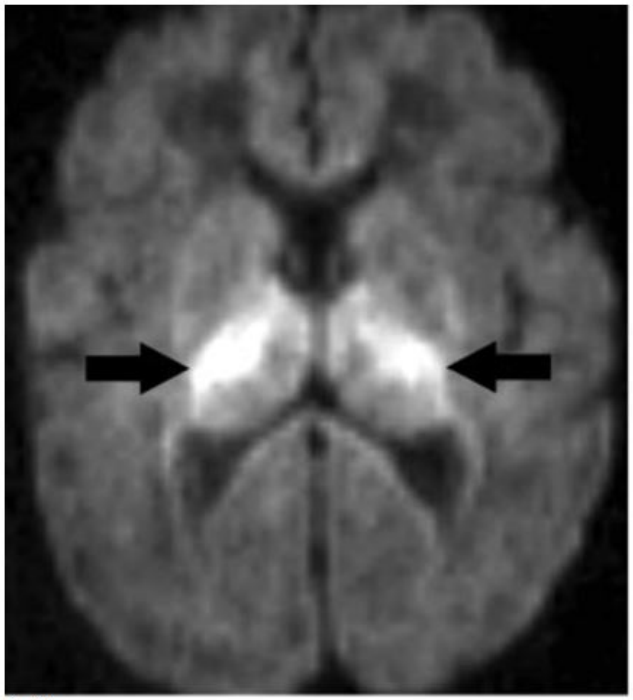


Fig. 5A

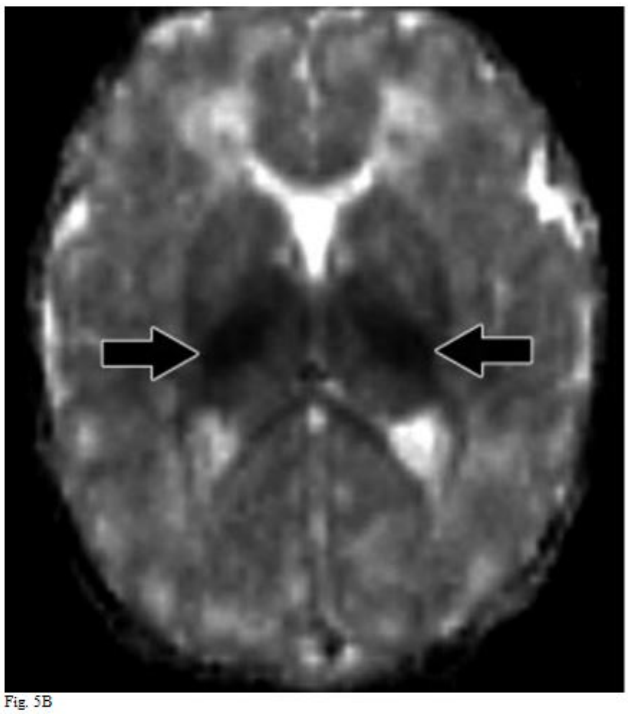
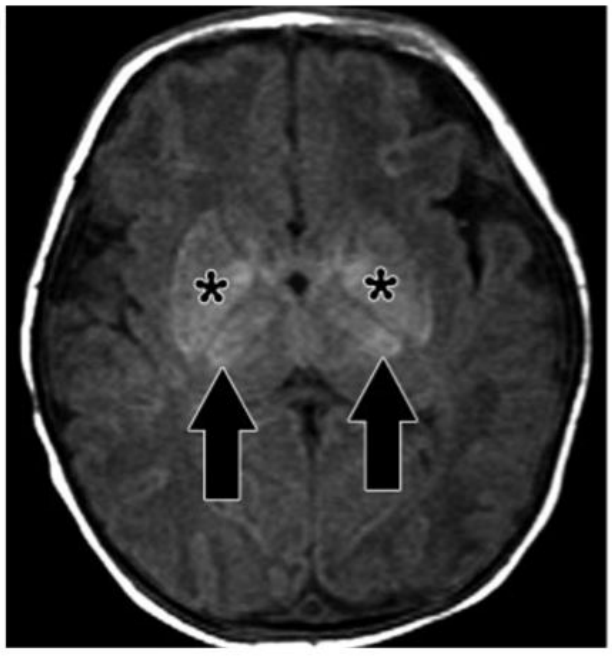


Fig. 5B

Figure 5: Severe profound HIE in a two day old term infant who suffered severe birth asphyxia.

A: DWI shows the increased signal in the bilateral ventrolateral thalami.

B: Corresponding low signal in the same regions on the concurrent ADC map, a companion sequence to the DWI, confirming that the findings are truly the result of ischemia (rather than artifact). HIE: Hypoxic ischemic encephalopathy. DWI: Diffusion-weighted imaging. ADC: Apparent Diffusion Coefficient. Radiographics 2008 Mar-Apr;28(2):417-39, reprinted with permission [7].



T1

Fig. 6A

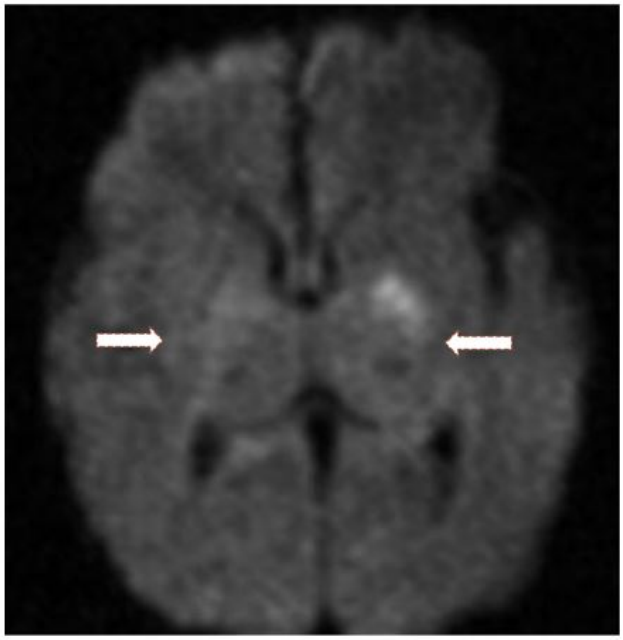


Figure 6: Pseudonormalization

A: T1 MRI in a 7-day-old term infant with HIE shows the increased signal in the lentiform nuclei (*) and ventrolateral thalami (black arrows).

B: Concurrent DWI shows a relative lack of hyperintensity in those regions affected on T1, with overall findings representing pseudonormalization (white arrows). This ages the injury as at least 7-10 days old. MRI: Magnetic resonance imaging. HIE: Hypoxic ischemic encephalopathy. DWI: Diffusion-weighted imaging. Radiographics 2008 Mar-Apr; 28(2):417-39, reprinted with permission [7].

Conversely, an MRI obtained two weeks after birth is less likely to be helpful for estimating the time of injury, as pseudonormalization might have occurred due to an injury in either the prenatal period or during the birthing process itself, or even postnatally. **Therefore, the authors strongly suggest that an MRI be obtained between 24 hours and six days of birth in cases of suspected HIE, as this confers the greatest chance that imaging will be able to help date the initial injury relative to birth.** Positive findings on an MRI obtained within this time frame can be used to help better differentiate injuries that occurred in utero from those that may have occurred during the birthing process. MRI's obtained after six days are less likely to be helpful in differentiating these injuries. ACOG guidelines also discuss that an initial MRI obtained between 24-96 hours of life is more sensitive for the timing of perinatal cerebral injury, however state that an MRI undertaken optimally at 10 days of life (with an acceptable window between 7 days and 21 days) will best delineate the full extent of cerebral injury on conventional imaging and helps to determine prognosis [12]. From a medicolegal perspective, these recommendations for "optimal" imaging are not necessarily helpful, as MRI's obtained between 7 and 21 days usually cannot be used to reliably time the injury. The imaging guidelines detailed in this paper are thus more likely to be helpful, particularly in the setting of litigation, than those proposed by the ACOG. If clinically warranted, a follow-up MRI may be obtained later on (such as during the 7-21 day window proposed by the ACOG), for prognostic purposes and to help determine the full extent of the injury, as opposed to helping time the injury. If only one MRI is to be obtained, some sources offer more specific suggestions of performing it at 3-5 days after birth, as this would hopefully allow for detection of findings on both DWI and conventional imaging [1,26]. As an additional note, given the chance of false negatives within the first 24 hours, some sources suggest that a negative MRI within the first 24 hours in cases of sus-

pected HIE should prompt a second MRI at 2-4 days [7]. While initial MRIs in patients with suspected HIE are often delayed for various reasons, doing so can result in missing a critical time window to obtain valuable diagnostic data as well as data that can become crucial in malpractice lawsuits. The authors of this paper recognize that some institutions may not have ready access to MRI machines, and emphasize that all clinical decisions should be made after a careful risk-benefit analysis, taking into account individual patient circumstances. We do not advocate rushing to perform imaging if there is a potential detriment to patient care. However, it is noted that nearly all patients with suspected HIE will undergo a brain MRI at some point to document the extent of involvement and prognosis. Rather than a delayed brain MRI which cannot accurately time the onset of injury, we suggest performing the MRI when it can age the injury with respect to birth, as long as there are no prohibiting factors.

Using Imaging to Help Determine Prognosis and Degree of Hypoxic-Ischemic Encephalopathy

Depending on the degree of oxygen deprivation, term neonates may demonstrate different imaging patterns ranging from mild or moderate to severe ischemic injury, with different parts of the brain being affected. In the neonatal brain, active myelination (a highly energy-intensive process) occurs primarily in the deep grey matter. In the event of fetal hypoxia, autoregulatory mechanisms preferentially shunt blood to maintain perfusion to these critical deep brain structures at the expense of the less metabolically active cerebral cortex [7,26,27]. Severe cases of HIE overcome the protective mechanisms of the neonatal brain, and imaging findings in these cases classically involve the deep brain structures including the basal ganglia, thalami, and dorsal brainstem (Figure 5 and Figure 4B). Other areas that can be involved include the hippocampi, lateral geniculate nuclei, corticospinal tracts, and sensorimotor cortex (also sometimes referred to as the perirolandic cortex) [7,20,23,34,35,39]. This pattern of injury is often referred to as a severe profound pattern.

In contrast, in cases of only mild to moderate HIE, neonatal protective mechanisms can preserve blood flow to the deep brain structures. Thus the regions of injury instead involve the cerebral cortex and subcortical white matter, particularly the intervascular watershed zones (Figure 7) [7,17,19,27,32, 34,35,39] The imaging pattern in these patients is often referred to as a partial prolonged pattern, and can be seen in such conditions which have a more protracted course, including but not limited to prolonged hypotension (such as in the setting of gradual cord or uterine artery occlusion), infection, and hypoglycemia [23,40].

The prognosis in patients who demonstrate a severe profound pattern of injury is poorer than those patients with partial prolonged injury patterns, with many cases resulting in neonatal demise and studies also showing a strong association between brain stem involvement and neonatal death [5]. Causes of this pattern of injury are the result of severe and prolonged asphyxia, such as uterine rupture, cord prolapse, or placental abruption [12,27] Additional antepartum causes of this pattern of injury include maternal cardiovascular collapse or fetomaternal hemorrhage [12,27]. While patients with both severe profound and partial prolonged patterns of injury can develop lifelong disabilities (including cerebral palsy, seizure disorders, developmental delay and motor function issues), patients with partial prolonged patterns of injury generally develop less severe forms of these conditions, and overall have a better neurological prognosis [5-8]. It should be noted that while these findings on MRI are useful in determining patient prognoses in cases of HIE, they are less helpful in navigating patient treatment options.

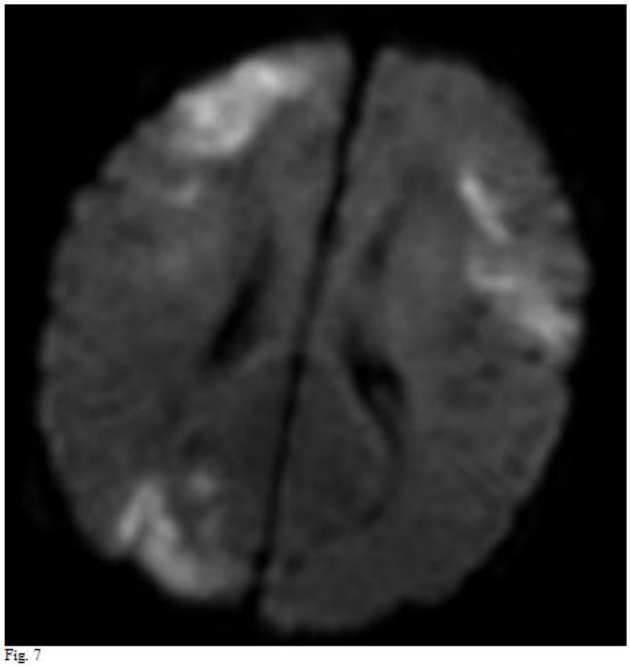


Figure 7: A partial prolonged pattern of neonatal HIE in a two day old term infant who experienced seizures shortly after birth. DWI shows restricted diffusion in the cortex and subcortical white matter in a watershed distribution. HIE: Hypoxic ischemic encephalopathy. DWI: Diffusion-weighted imaging. Radiographics 2008 Mar-Apr;28(2):417-39, reprinted with permission [7].

In considering differential diagnoses for hypoxic ischemic encephalopathy, it's important to note that one possible disadvantage of utilizing MRI to diagnose HIE is the potential for overlapping clinical and brain MRI findings between HIE and inborn errors of metabolism (IEM) [41,42]. A single temporal brain MRI may not be able to distinguish HIE and IEM because both involve the basal ganglia, thalamus, cortex, and white matter. However, HIE is the result of a singular event occurring before or during birth, while IEM is a continuous life-long metabolic disorder which results in continuing brain injury well past the neonatal stage. Therefore, diffusion weighted imaging (DWI) showing new regions of brain injury on subsequent delayed MRI scans would be consistent with IEM, rather than HIE. In patients where the diagnosis is not clear-cut, direct diagnostic and/or genetic testing may be useful for further evaluation. The experience level of the interpreting radiologist in such cases is of vital importance; as such diagnoses are relatively rare and may only demonstrate subtle findings on imaging.

Preterm Infants

The guidelines for interpreting imaging in HIE for term infants (greater than 36 weeks) do not apply to preterm infants (less than 36 weeks). Various structures do not undergo myelination until 35-37 weeks, leading to differences in findings [7,20,24,34,35,39]. As such, the timing of HIE in preterm infants by imaging is a unique endeavor and beyond the scope of this paper. In terms of prognosis, severe profound patterns of injury in preterm infants demonstrate similar imaging findings to term infants, with involvement of deep brain structures such as the basal ganglia and thalami [39]. However, partial prolonged injury patterns in preterm infants preferentially involve the periventricular white matter, rather than the more peripheral subcortical and parasagittal white matter involved in term infants. This is due to the fact that in term infants flow is compromised to ventriculofugal vessels in subcortical watershed zones, however in preterm infants these vessels run in a ventriculopedal pattern, leading to the preferential involvement of the periventricular white matter in preterm infants [39].

Conclusions

In cases of neonatal HIE, medical imaging can play a vital

role in determining when the injury occurred. Ultrasound and MRI performed at the appropriate times can help providers to determine if an injury was likely to have occurred intrapartum or in utero. These studies could provide vital, objective data when there is litigation and disagreements between expert opinions regarding injury timing. However, imaging studies obtained too late after birth will be ineffective for differentiating an in utero injury from an intrapartum injury. Therefore, it is imperative that imaging studies be obtained early on in cases of suspected HIE. Some healthcare professionals may not be aware of the optimal time frame for imaging infants with suspected HIE and thus often miss the opportunity to obtain vital diagnostic data by delaying certain imaging studies. The imaging suggestions outlined in this article offer the best chance of establishing an accurate timeline of the injury leading to HIE, with the specific imaging findings discussed being essential for injury timing as well as patient prognosis.

Declarations of Interest

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