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# Advances in neonatal brain imaging: A comparative analysis of MRI, CT scans, and ultrasound

Arwa O. Baeshen [1], Naif H. Almutairi [1], Othman I. Alomair [1], Dhafer M. Alahmari [2], Magbool Alelyani [3], Sami A. Alghamdi [1, *]

[1]*Department of Radiological Sciences, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia*
[2]*Department of Medical Imaging, King Saud Medical City, Riyadh, Saudi Arabia*
[3]*Department of Radiological Sciences, College of Applied Medical Sciences, King Khalid University, Abha, Saudi Arabia*

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ABSTRACT

This scholarly investigation undertakes a comprehensive comparison of the diagnostic efficacy, precision, and sensitivity associated with neonatal brain Magnetic Resonance Imaging (MRI) in contrast to its counterparts, Computed Tomography (CT) scans and ultrasound. As the medical community has progressively become attuned to the long-term health implications of radiation exposure from CT scans, the imperative of a strategy mitigating this risk has gained prominence. In this context, ultrasound emerges as an alternative modality devoid of ionizing radiation. Employing a methodical approach rooted in systematic literature review, this study synthesizes five pertinent research works to unravel its research objectives. Empirical evidence substantiates that neonatal brain MRI surpasses both neonatal brain CT and ultrasound in diagnostic effectiveness. The underpinning rationale for this phenomenon lies in the heightened accuracy inherent to neonatal brain MRI procedures. To unravel the intricacies associated with disparities between neonatal and adult brain MRI procedures, the study meticulously investigates structural, shape, and size distinctions. This endeavor underscores the necessity for bespoke MRI apparatuses designed to account for these nuances. In pursuit of this objective, the integration of technologically advanced components such as compact scanners and refinements in magnetic and coil technologies has engendered tangible improvements. This innovation confluence bears testimony to the augmentation of patient safety, conferring a cascade effect wherein the precision of acquired MRI data underwrites accurate diagnoses and consequent therapeutic interventions. Conclusively, the study underscores the pivotal role played by recent MRI technological advancements in amplifying its efficacy within the niche domain of neonatal brain imaging. Prospective innovations within the MRI ambit stand poised to recalibrate performance benchmarks, thereby amplifying its diagnostic potency and broadening its scope of application.

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## 1. Introduction

Neonates, or infants in their earliest stages of life, represent intricate and dynamic organisms highly susceptible to an array of both infectious and non-infectious disorders and afflictions. This heightened vulnerability underscores the imperative for a robust immune system equipped with swift-response mechanisms poised to mobilize instantly upon accurate identification, subsequently deploying their resources. In contrast, the immune system of a newborn is still undergoing an intricate and gradual process of maturation, marked by intricate transformations (Yu et al., 2018; Khan, 2021). In the case of newborns presenting with symptoms of neonatal encephalopathy (NE), seizures, unexplained apneas, infections, metabolic disorders, birth traumas, or suspected structural brain abnormalities, brain imaging is an essential part of the diagnostic and therapeutic process. A wide range of methods are used worldwide for pediatric, neonatal, and fetal brain imaging. The most commonly used methods are head ultrasound (US),

* Corresponding Author.
Email Address: salghamdi1@ksu.edu.sa (S. A. Alghamdi)
https://doi.org/10.21833/ijaas.2023.08.006
Corresponding author's ORCID profile:
https://orcid.org/0000-0002-6404-8762
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magnetic resonance imaging (MRI), computed tomography (CT), or a combination of these. However, there is no clear preference for an imaging modality that has become standard in all medical institutions at the moment. Individual physicians make decisions based on which technique has the best accessibility, cost-effectiveness, and radiation exposure at the time. To effectively address this pressing public health concern, we must first get a deeper understanding of the disruptions to typical brain development that lead to behavioral disorders in young children. Linking brain and behavioral changes in vivo is essential for expanding our understanding of these mechanisms because postmortem studies have inherent limitations, such as the inability to assess relationships with functional outcomes, sample scarcity, the reasons for the death of available specimens, and tissue fixation. Our understanding of the brain has been profoundly altered by the advent of noninvasive neuroimaging techniques like MRI over the past two decades (Dubois et al., 2021; Sorokan et al., 2018).

MRI has been a valuable tool for assessing brain development and detecting brain abnormalities in both preterm and term newborns. Other imaging modalities, such as CT scans and head the US, are still used in some radiology departments today. However, given the vast differences between neonatal and adult brains, it is clear that MRI advancements are better suited to meet technological challenges. The size, shape, and overall maturity of brain tissue differ between adult and neonatal brains. This means that for better images of the 'neonate's brain, a higher resolution and a high Signal-to-Noise ratio (SNR) must be obtained in the shortest scanning time possible (Dubois et al., 2021). To accomplish this, changes to the MR sequences, the use of stronger magnets, and receiver coil advancements should be made. With these enhancements, MRI imaging may outperform other modalities such as CT or US in terms of diagnostic imaging for neonates. However, MRI is not the quickest method of medical imaging and requires the patient to remain as still as possible during the scanning process to avoid artifacts in the images. Persuading a young infant to lie still for 20-30 minutes during scanning sessions could be difficult. Fortunately, adaptation to this challenge has resulted in the development of a number of novel techniques and tools, such as the cradle and the MRI-compatible incubator (Tkach et al., 2014; Bekiesińska-Figatowska et al., 2019). Another safety concern that imaging professionals must keep in mind during scanning sessions is that the child does not come into contact with metal or other non-MR-approved materials that could cause potential skin burning. Another advancement in assisting the imaging professional in neonate MRI has been the sedative options available (Picone et al., 2019). There are still additional risks when prescribing sedatives to such a young child with a developing brain. While sequential imaging of newborns in the US has been routine in a number of medical institutions, MRI has proven to be superior to the US in detecting white matter and cerebellar abnormalities and is gaining popularity among medical professionals (Fumagalli et al., 2018). Because of the lack of ionizing radiation, MRI is quickly becoming the preferred method. When it comes to neonatal neuroimaging, professionals can provide a safe alternative. This also allows for high-resolution images and increased safety in neuroimaging. Using the higher magnetic fields of the MRI, temporal and spatial resolution can be improved by a higher signal-to-noise ratio in order to meet the smaller field of view required in imaging newborns.

MRI should be compared to other imaging modalities. US, also known as US/CUS, was first used in neonatal intensive care units in the 1970s. The availability, cost-effectiveness, and non-invasive method in which it could be used contributed to its popularity. The US also brought a number of advantages, such as the ability to process images with little or no disruption to the infant. Even if the child was on a ventilator, this was true. Images could be taken without the use of potentially dangerous sedatives. However, it did not take long for the imaging modality to develop a number of flaws. It was discovered that the imaging process was overly reliant on the operator, the machine, and the probe all working properly at the same time. It was also difficult to obtain a complete view of the brain's periphery, such as along the posterior fossa. White matter injuries and interobserver variability were nearly impossible to diffuse accurately due to poor visibility (Audrey and Procter, 2015; Dudink et al., 2020). Cerebellar hemorrhages were also discovered to be difficult to detect due to the distinction between frequency, extent, and sequelae. When MRI is unavailable, CT is the next best option for a number of medical imaging professionals. While CT has some advantages over MRI, such as greater sensitivity in detecting calcifications, the potential risks of radiation exposure have reduced its use. When comparing the overall function of CT and MRI, the MRI detects abnormalities in white matter changes, gyration, and cerebellar hypoplasia with a higher success rate (Ibrahim et al., 2018; Smiljkovic et al., 2019).

This review will be focused on four research objectives; (i) to demonstrate the importance of MRI for 'neonate's brain imaging in comparison to CT scan and US, (ii) to demonstrate the technical challenges for neonates and brain imaging and the differences between 'adult's brain, (iii) to introduce advancements in magnetic strength, advancements in coil technology, and (iv) to demonstrate how new advancements in technology and techniques have provided a better and safer process in imaging neonates.

MRI was discovered to be a more sensitive method of detecting white matter abnormalities. According to Ibrahim et al. (2018), cerebellar hemorrhages were also easier to detect, even when they were smaller in size. These types of hemorrhages were discovered to be linked to poor neurodevelopmental outcomes in preterm neonates (Ibrahim et al., 2018).

While CT has been shown to be the most sensitive in detecting calcifications, the health risks associated with radiation exposure have discouraged medical professionals from using CT as their primary neuroimaging modality. The US has also seen a number of advancements that have improved this method's ability to detect calcifications. When compared to CT, MRI has a higher rate of detecting abnormalities in white matter changes, gyration, and cerebellar hypoplasia. A study was conducted by Smiljkovic et al. (2019) to observe assessment concordance between the US and the use of MRI or CT when identifying neurological abnormalities in infants with cCMV infection. The study attempted to determine whether the United States required additional advanced neuroimaging. Between January 2008 and December 2016, 46 infants were diagnosed with cCMV infection at the Centre d'InfectiologieMère-Enfant (CIME) at the Centre HospitalierUniversitaire Sainte-Justine (CHUSJ) in Montreal, Canada. The first 34 infected patients had sequential baseline imaging with the US, followed by MRI (n=28, 61%) or CT (n=6, 13%). On two of the patients, CT was used as the primary study, followed by MRI. The top ten used a single modality, either US, CT, or MRI. 39 (85%) of the patients tested had images taken with the US as the first or only modality. The remaining six (15%) patients received either CT or MRI first, or only neuroimaging. Patients who had their initial test using either MRI or CT were more likely to have SNHL at the time of diagnosis. The study found that sequential imaging with US and MRI or CT was concordant in 71% of cases when it came to detecting abnormalities associated with cCMV. While US was shown to have a high success rate in detection, MRI follow-up imaging provided more accurate results (Smiljkovic et al., 2019).

Another difference between MRI and US imaging was discovered by Harvey and Redshaw's (2016) studies in terms of effective communication techniques between parents and medical professionals. The qualitative study focused on the interaction and communication between medical professionals and parents of preterm babies following brain US and MRIs. The interaction and communication were divided into three themes in the study. Giving information, Managing the conversation, and Getting it Right were the themes. The study discovered that using MRI images when discussing issues with parents in cases with potentially negative outcomes may become more common (Harvey and Redshaw, 2016).

MRI is commonly used to evaluate neonates for diagnosis and prognosis. According to a previous study, it has several advantages over the US, including high contrast resolution. The author goes on to show that, when compared to the US, MRI has a higher contrast resolution between normal and abnormal brain tissues. Furthermore, it can provide more comprehensive coverage and multiplanar imaging capabilities. According to Likeman (2014), the hydrogen nucleus is used for imaging purposes due to its abundance in fat and water. Tkach et al. (2012) demonstrate the feasibility and potential of the neonatal MRI system in providing cutting-edge MRI capabilities within the Neonatal Intensive Care Unit (NICU). The advanced version lowers costs and site demand, improves accessibility, reduces auditory noise, and lowers medical risks to the neonate. The use of MRI reduces the medical risks and logistical difficulties associated with transferring premature infants from the NICU to a radiology department (Tkach et al., 2012).

While MRI is useful for imaging the brains of pediatric, neonatal, and fetal patients, there are several issues that must be addressed. MRI imaging, for example, takes longer than CT or other imaging modalities. An adult can lie down and wait until the procedure is finished without moving much. Infants who are exposed to loud noises, on the other hand, will struggle to stay still long enough to produce images free of artifacts. This is due to the fact that neonatal imaging requires the child to be as still as possible in order to avoid artifacts that may be difficult to diagnose in cases where there is a problem. To compensate for this, imaging departments must hire more apprentices to help with the process. However, this equipment is quite expensive, limiting the ability of a number of clinics to perform such imaging. When detecting anomalies in a much smaller brain, there are also developmental concerns (Nopoulos et al., 2000).

When compared to a neonate, the adult brain has a significant size difference. The head of a child is much larger in proportion to its body. As a result, the muscles and ligaments in the infant's neck have difficulty supporting the weight, which frequently results in head and cervical spine injuries. A child's brain can be nearly 25% the size of an adult's while being fundamentally different physiologically and anatomically. Babies also go via rapid neurological developmental stages, necessitating the use of different segmentation algorithms to determine the child's stage during imaging. Adult brains have already gone through the natural developmental process, and a variety of templates can be compared when looking for abnormalities. However, there are fewer templates to compare with in infants, making identification of abnormalities much more difficult. With few templates to compare, detecting a variety of anomalies can be difficult (Devi et al., 2015; Shi et al., 2010; Li et al., 2019).

During the neurological development stage, the appearance of the adult and neonatal brains is also quite different. When comparing an image of a newborn child to that of an adult, it is immediately apparent that the child lacks the folds seen on the surface of the adult brain. Short-distance fibers will form and neural connections will form over time. The visible fold will form over time, and with a much smaller area to observe, imaging professionals risk mis-identifying or failing to detect abnormalities that would normally be seen in an adult brain (Dubois et al., 2021).

New developments in newborns and infants MRI Since the early days of medical imaging, there have been numerous advances that have led to the modern methods that are used today. Imaging tools, sedation chemicals, and procedures are all becoming more compatible for use on neonates during each developmental stage. One of the most difficult challenges for imaging professionals is reducing the number of artifacts caused by the child moving or crying during imaging. Sedatives should be avoided in neonates because their brains are constantly maturing at a rapid rate. However, with improved techniques and imaging modality advancements, these issues are starting to be addressed (Lindberg et al., 2019).

The requirements for infants and younger children undergoing an MRI differ from those for adults. Infants, for example, require a much smaller field of view and a much higher signal-to-noise ratio in order to have better temporal and spatial resolution. Higher magnetic fields can deliver what is required. When imaging infants, however, a number of safety precautions must be taken into account (Fumagalli et al., 2018; Chartier et al., 2019).

Coils designed specifically for infants can provide a number of advantages when performing MRIs. Coils can compensate for the size ratio of a smaller child's body and head in order to improve the signal-to-noise ratio (SNR). Using dedicated coils in images with a gain greater than x2, the SNR is critical when imaging brain regions and their proximity to the coil. This is a significant benefit because it reduces the number of images with artifactual anomalies caused by the child's movement during the long period of time required for an MRI. The repetition time (TR) and echo time (TE) are important in controlling the image contrast and weighting of an MRI image. Due to the small size of an infant's brain, these must be timed correctly in order to obtain a more coherent view of the image area. Controlling these areas is critical when attempting to detect smaller abnormalities that may be more difficult to detect than in the adult brain (Dubois et al., 2021; Hughes et al., 2017; Malamateniou et al., 2013).

Because of the high possibility of motion artifacts in small children, sedatives are sometimes the only way to obtain quality images successfully. Picone et al. (2019) proposed the use of melatonin for infants undergoing MRI scans. In the study, infants were given 10 mg of melatonin orally 30 minutes before the exam, regardless of body weight. All the children who participated in the study fell asleep after 35 minutes of administration. Over 55% of the tested children had a successful MRI session. Sleep deprivation, in addition to the administration of sedatives, can improve the rate of success. The test also revealed that there had been no reports of adverse effects (Picone et al., 2019). Future research may lead to the discovery of new methods or chemicals that provide greater safety and lower risks. There are several safety concerns that must be addressed when undergoing MRI imaging. While there is no danger of radiation exposure, there are other issues to consider, such as absorption rate and the possibility of burning if non-MR-approved materials come into contact with the child's skin. This could occur as a result of radio frequencies interacting with a material such as metal pins or buttons. There are also a number of physical safety risks to consider. For example, items that could cause a tripping hazard or cause the child to be dropped must be removed from the room. If an adult is assisting the child, that person's safety must also be considered (Fumagalli et al., 2018).

MRI is generally regarded as a safe imaging technique. Current research shows no evidence of severe harm to human tissues. MRI, on the other hand, is linked to loud acoustic noise, peripheral nerve stimulation, and tissue heating. Early MRI scans in infants are difficult to perform and frequently necessitate respiratory support. These scans are susceptible to hemodynamic variation. As a result, they should be carried out in a safe and controlled clinical setting using specific procedures and protocols. When safety procedures are followed, there are no known long-term health risks associated with an MRI examination. Minor MRI scan risks include excessive sedation, which poses a minor risk, and some patients are likely to experience claustrophobia. Furthermore, medical implants containing metal may malfunction, causing problems, and allergic reactions may occur as a result of exposure to certain materials. Sedation and anesthesia can also result in difficulty breathing and low blood pressure. Patients with impaired kidney function may develop nephrogenic systemic fibrosis. Prior consultations with clinicians can aid in the management of these minor risk factors (Plaisier et al., 2012). MRI-compatible incubators provide a safe, temperature-controlled environment for scanning newborns. As a result, they provide acceptable image quality while avoiding sedation in many cases. Patient adverse events are rare in MRI-compatible incubators. Overall, they have improved MRI safety for newborns, resulting in better image quality and treatment outcomes. They remain to be important research resources for preterm and term babies with brain injury. MRI-compatible incubators are now available, improving access to imaging for younger, smaller, and sicker babies in medical settings. In the future, the devices will allow more unusual imaging procedures to be used on this vulnerable population. According to Lane et al. (2013), it will facilitate translational research, which is critical in investigating how to improve neurodevelopmental outcomes in preterm infants.

## 2. Methodology

The use of computerized tomography ('CT') scans, positron emission tomography (PET) scans, and x-ray scans in brain scanning have been associated with future health implications for patients. The rationale for these concerns is that ionizing radiation can damage 'patients' DNA and causes cancer (Smiljkovic et al., 2019). In recent years, there have been concerted efforts aimed at ensuring that alternative imaging approaches are adopted and used in the diagnosis and monitoring of 'neonates' brains. The alternative imaging approach, whose efficacy is tested in this study, is MRI (Tkach et al., 2014). The study adopts a mixed research design to answer the research questions. In its data collection, secondary data sources are used. These include literature on the use of MRI in neonate brain imaging. Subsequently, the study adopts a systematic literature review. Subsequent sections of this chapter identify the search strategy used, the inclusion criteria, and the intended coding approach.

Before conducting a systematic literature review, it is essential to develop a list of search terms. It is these terms that lead a researcher to relevant pieces of literature. According to Xiao and Watson (2019), this is achievable considering that the search terms usually reflect the key themes which also appear in previous studies. There also exist various databases, and as such, only relevant databases must be relied on when identifying relevant pieces of literature. In this study, an electronic database, PubMed, was used. The databases identify those known to host evidence-based clinical imaging resources regarding the importance of MRI in neonate brain imaging compared to other scans such as CT scans and the US. The electronic databases included four electronic journals. These journals were the Journal of Pediatrics, Journal of Neuroradiology, American Journal of Neuroradiology, and the Journal of Pediatric Radiology. The search for these journals was conducted in the PubMed database (Xiao and Watson, 2019).

The first search terms consisted of "brain MRI," "challenges in neonatal brain imaging," "coil technology," and "safe neonates imaging." The second search terms included combinations of "importance," "MRI," "neonate brain," "MRI strengths," and "new advancements in MRI." These search terms were entered into the four electronic databases of the journals that had been identified for the study. To combat the possibility of publication bias, apart from the electronic searches in the four electronic sources, additional searches were conducted for both published and unpublished evidence. Apart from bias, another rationale for consulting additional sources is premised on the fact that depending fully on publications in the four data sources would lock out quality studies on the search question. Considering that the study fully relies on electronic databases, an electronic search of additional relevant literature is conducted in the OpenGrey database. The database is a unique open-access resource database that stores unpublished research and student theses (Duftner et al., 2018).

To ensure that only up-to-date journal articles are included in the study, only studies published within the last twenty years are included (from 1st January 2001 to March 2021). The study relies on studies that investigate the clinical application of MRI in neonates' brain diagnostic imaging in comparison to CT scans or the US. As observed by Harvey and Redshaw (2016), diagnostic accuracy studies usually avoid the conducting of randomized control study design considering the ethical questions that accompany the approach. Plaisier et al. (2012) argued that diagnostic test accuracy studies should adopt either prospective or retrospective cohort and case-control study design approaches. Subsequently, only studies with prospective or retrospective cohort designs are considered in the review. Another inclusion strategy is that for a study to be included, it must have enrolled patients who were initially evaluated using a CT scan or the US before being evaluated using MRI. Additionally, the studies must have evaluated MRI neonate brain images against similar images captured using CT scans or the US. The studies included in the research must also include new technological innovations currently enhancing the use of innovative breakthroughs in MRI neonatal imaging. Further, in their outcomes, the studies included must measure the diagnostic accuracy estimates of the MRI neonate brain scan against CT scan and the US. Subsequently, the studies must report factors such as the sensitivity and specificity of the diagnostic tools in detecting and quantifying brain abnormalities (Plaisier et al., 2012).

## 3. Results and discussion

The electronic literature search strategy adopted for the study yielded a total of 36 potentially useful studies. The studies were spread across the journals as follows; the Journal of Pediatrics (11), Journal of Neuroradiology (9), American Journal of Neuroradiology (8), and the Journal of Pediatric Radiology (7). As stipulated in the methodology, these resources were further screened for eligibility. The process adopted is indicated in the PRISMA flow diagram (Fig. 1). In the initial skimming of the 36 studies, 23 studies were eliminated due to the irrelevance noted in both their titles and abstracts. Subsequently, the full texts of the other 13 studies were retrieved for purposes of more detailed screening as per the inclusion and exclusion criteria developed for this study (Table 1). Three more studies were removed on the grounds that although they focused on comparing the use of MRI and CT scan in evaluating neonate brain they included participants aged more than 28 days. Additionally, two more studies were excluded because despite focusing on both MRI and CT scans or US in neonate brain scans, they did not report comparisons between diagnostic performances between the imaging approaches. As such, it was impossible to assess the diagnostic sensitivity, accuracy, and specificity in diagnosing brain abnormality among neonatal patients. Another three studies were excluded from the current study considering that they evaluated the features of neonate brain images produced by both MRI and CT or US without providing diagnostic accuracy measures.

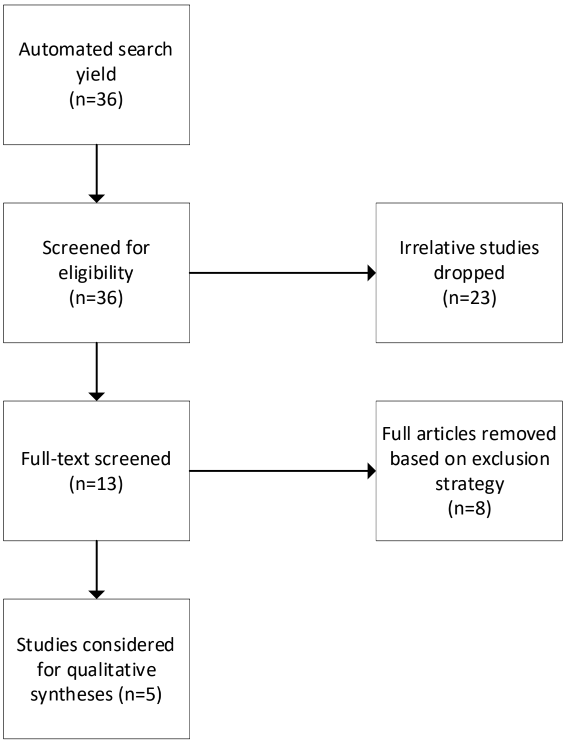


**Fig. 1:** PRISMA flow chart for the selection process of the included studies

**Table 1:** Inclusion and exclusion criteria used in this study

| Inclusion criteria | Exclusion criteria |
|---|---|
| A comparative study that evaluates the sensitivity and specificity of MRI in the diagnosis of neonate brain abnormality | Non-comparative studies, including reviews and technical reports that evaluate only the technical application of MRI and CT or ultrasound in the detection of neonate brain abnormality |
| Studies that enroll neonate patients with a suspected brain abnormality | studies focusing on the use of MRI in brain imaging without focusing on neonate patients |
| Studies involving neonate patients (<28 days | Studies involving adult patients |
| Studies that compare the diagnostic performance between MRI and CT or ultrasound in terms of sensitivity, accuracy, and specificity in diagnosing brain abnormality among neonatal patients. | Studies that do not report comparisons between diagnostic performance between MRI and CT or ultrasound in terms of sensitivity, accuracy, and specificity in diagnosing brain abnormality among neonatal patients |
| Studies that are published in the English language | Studies that are published in languages other than the English language |
| Studies published in the last 20 years | Studies were published more than twenty years ago |

Consequently, five studies were included in this study's review for qualitative review (Maalouf et al., 2001; Robertson et al., 2003; Leijser et al., 2007; Chau et al., 2009; Intrapiromkul et al., 2013). All five studies were prospective cohort studies considering that their diagnostic accuracy was found in Table 2. This implied that they met all the provisions of the inclusion criteria for this study. The outcomes in this section are summarized in Table 2.

### 3.1. Methodological quality and consistency

For purposes of evaluating the relevance of the chosen studies, QUADAS-2 was adopted. The adoption of the approach was in contrast to popular assertions that there exist more logical strategies that provide more logical results compared to QUADAS-2. Table 3 indicates the presentation of data through the use of simpler ratings.

### 3.2. Study characteristics

The studies evaluated jointly have 212 participants. The largest sample is that of Robertson et al. (2003), which included 85 study participants. In the study, both neonates and near-term neonates were included in the study. Chau et al.'s (2009) study, on the other hand, had the highest number of participants at 48. The participants were a cohort of term newborns with neonatal encephalopathy. The study with the third-highest number of participants was Leijser et al. (2007) which had 35 participants. These participants were neonates with metabolic disorders. Maalouf et al.'s (2001) study came fourth with 32 participants. The participants were infants born at or below the gestational age of 30 weeks. The participants had equally undergone a cranial US scan and MRI on the same day. The infants equally underwent, whenever possible, three scans between the time of birth and the time of the scan. The smallest sample consisted of 12 participants and was authored by Intrapiromkul et al. (2013). The mean age for the participants was 9.8 days. The youngest of the neonates was three days old, while the oldest was twenty-three days old. The mean gestational age of the study participants was 32.8 weeks. While the lowest gestational age was 29.6, the highest was 35.4 weeks.

**Table 2:** Five cohort studies considered for diagnostic accuracy are listed below

| Reference | Study design and evidence level | N | Patient characteristics | Index diagnostic imaging tests | Reference standard | Diagnostic test performance |
|---|---|---|---|---|---|---|
| Maalouf et al. (2001) | Prospective cohort studies Level of diagnostic accuracy evidence 1b | 32 | Infants born at or below a gestational age of 30 weeks | Participants underwent cranial US scan and MRI on the same day Infants underwent, whenever possible, 3 scans between birth and term Sixty-two paired MRI and US studies were performed between birth and term in 32 infants born at a median gestational age of 27 (range: 23–30) weeks and a median birth weight of 918 (530–1710) grams. | Presence of germinal layer hemorrhage (GLH), intraventricular hemorrhage (IVH) and severe white matter in cranial ultrasound and MRI | MRI exhibited a sensitivity of 91% Ultrasound exhibited a sensitivity of 89% in detecting the presence of GLH, IVH, and hemorrhagic parenchymal infarction |
| Robertson et al. (2003) | Prospective cohort studies Level of diagnostic accuracy evidence 1b | 85 | Neonates aged below 28 days old with suspected brain complications | CT and MR examinations were obtained within 72 h of one another in all 85 patients. CT scan was obtained using 5 mm collimation (KV=120, mAs=340). MR was obtained using T1-weighted imaging (TR/TE=300/14; 4-mm slice thickness/1-mm gap), T2-weighted imaging (TR/TE/etl= 3000/126/16; 4-mm slice thickness/1-mm gap), and line scan diffusion imaging (LSDI) (TR/TE/b factor=1258/63/750; nominal 4-mm slice thickness/3-mm gap) | Confirmation of whether the brain was normal or abnormal on both CT and MRI | MRI exhibited a sensitivity of 93.8% while CT scan had a sensitivity of 83.3% |
| Leijser et al. (2007) | Prospective cohort studies Level of diagnostic accuracy evidence 1b | 35 | Neonates who had a history of metabolic disorders and had had at least 1 US scan were eligible for the study. | The ultrasound images were reviewed for anatomic and maturation features, cysts, calcium, and other abnormalities. The ultrasound images would later be compared with MR images | The standard references included detection of oxidative phosphorylation disorders, ventricular dilation, germinolytic cysts and abnormal white matter. Other references included peroxisomal biogenesis and lenticulostriate vasculopathy | Ultrasound was found to exhibit a sensitivity of 91.8% in detecting neonatal metabolic disorders while 84.9% sensitivity was noted |
| Chau et al. (2009) | Prospective cohort studies Level of diagnostic accuracy evidence 1b | 48 | Newborns not exceeding more than three days and who have 36 or more gestation weeks admitted with neonatal encephalopathy | Patients were scanned with computed tomography, MRI, and diffusion-weighted MRI at 72 (±12) hours of life | The standard used involved the identification of predominant patterns of brain injury using CT scan and MRI. The patterns sought included normal, watershed, basal nuclei, total (maximal basal nuclei and watershed), and focal-multifocal (presence of strokes and/or white matter injury alone). | Diffusion-weighted MRI has the highest sensitivity technique that can be used in assessing brain injury among the study participants at 94.1%. MRI came second at 90.4%, while CT's sensitivity was gauged at 89.1% |
| Intrapiromkul et al. (2013) | Prospective cohort studies Level of diagnostic accuracy evidence 1b | 12 | Neonates with suspected intracranial hemorrhage. The neonates ages were between 3 and 23 days. They were also expected to have been of gestational age of 29 days and above | Ultrasound (US) and MRI scans of the brain were conducted to test I-III germinal matrix hemorrhage (GMH), periventricular hemorrhagic infarction (PVHI), intra-axial hemorrhage other than PVHI, and extra-axial hemorrhage in each cerebral hemisphere | Ultrasound was specific in the evaluation of grade III GMH, whereas SWI was better than detecting small intra-axial or extra-axial hemorrhage, and had no impact on short-term management | Ultrasound has a sensitivity of 100% and specificity of 93.3%. HUS had high sensitivity |

**Table 3:** Indicates the presentation of data through the use of simpler ratings

| Reference | Risk of bias | | | | Applicability concerns | | |
|---|---|---|---|---|---|---|---|
| | Patient selection | Index test | Reference standard | Flow and timing | Patient selection | Index test | Reference standard |
| Maalouf et al. (2001) | Low risk | Low risk | Low risk | High risk | Low risk | Low risk | Low risk |
| Robertson et al. (2003) | Low risk | Low risk | Low risk | Medium risk | Low risk | Low risk | Low risk |
| Leijser et al. (2007) | High risk | Low risk | Low risk | High risk | Medium risk | Low risk | Low risk |
| Chau et al. (2009) | Low risk | Low risk | Low risk | Medium risk | Low risk | Low risk | Low risk |
| Intrapiromkul et al. (2013) | Low risk | Low risk | Low risk | High risk | Low risk | Low risk | Low risk |

All the studies used in this review were equally comparative, having evaluated differences in the performance of MRI and CT scans or US in neonatal brain imaging. Their only differences were the nature of brain complications they sought to identify. For instance, in the Maalouf et al. (2001) study, a comparison between the application of MRI and US in accurately detecting germinal layer hemorrhage (GLH), intraventricular hemorrhage (IVH), and severe white matter (WM) echogenicity in neonatal's brains was tested. In Robertson et al.'s (2003) study, the researchers sought to assess the differences in the accuracy of MRI and CT scans in testing cross-modality agreement in brain imaging of neonates. In the Leijser et al. (2007) study, the primary objective was to investigate the range of abnormalities observed in a neonate's brain US. This was conducted on participants with metabolic disorders. The secondary aim was to address whether brain MR imaging is more informative than US images. In the Chau et al. (2009) study, the researcher focused on comparing the patterns of neonatal brain injury as generated in CT and conventional MRI or diffusion-weighted MRI. Lastly, for Intrapiromkul et al. (2013), the researchers evaluated the sensitivity and specificity of neonatal brain US in the detection of intracranial hemorrhage in comparison with brain MRI. The comparisons are essential considering recent years have been characterized by investigations inefficacy of MRI sequence in diagnosing brain-related complications. As such, the current study can demonstrate the importance of MRI for neonate brain imaging, the advancements in magnetic strength in coil technology, and advancements in technology and techniques that have provided a better and safer process for imaging neonates.

As previously stated, the use of computerized tomography in neonatal brain imaging has been scrutinized by researchers considering the likely future impacts on patients' health. Subsequently, other approaches such as US and MRI have been identified as the likely alternatives (Robertson et al., 2003). However, it is also evident that these approaches differ in terms of sensitivity when used concurrently in neonatal imaging. For instance, the studies analyzed in this research indicate that while MRI is more sensitive in detecting brain complications in neonates compared to CT scans, the US tends to be more effective and sensitive. The deeper analysis further indicates that MRI turns out to be effective in analyzing larger areas compared to the US (Groenendaal and Vries, 2017). To ascertain the specific findings regarding the application of MRI, CT scan, and US in neonate brain imaging, this section further relies on additional literature apart from the five reviewed. The additional studies will help ascertain reviewed literature's position on the importance of MRI for neonate brain imaging in comparison to CT scans and the US. Further, they will help in enhancing understanding of the advancements in magnetic strength, advancements in coil technology, and other tools that have provided an innovative breakthrough in neonatal imaging. Lastly, they will be applied in analyzing new advancements in technology and techniques that have provided better and safer processes in imaging neonates.

Maalouf et al. (2001) compared the application of MRI to the application of US in accurately detecting germinal layer hemorrhage (GLH), intraventricular hemorrhage (IVH), and severe white matter (WM) echogenicity in neonates' brains. Considering that 62 paired MRI and US studies were undertaken, the study's results indicated that the US conducted precisely predicted some of the MRI findings. Such results were realized when testing the presence of germinal layer hemorrhage, intraventricular hemorrhage, and severe white matter (WM) echogenicity. However, US could not predict the presence of DEHSI and small petechial hemorrhages in the WM. Further, the study realized that normal echogenicity on US was not reliable in predicting normal WM signal intensity on MRI. Subsequently, in terms of sensitivity, MRI was found to have a sensitivity of 91%, while US exhibited a sensitivity of 89% in predicting germinal layer hemorrhage (GLH), intraventricular hemorrhage (IVH), and severe WM echogenicity in neonates' brains (Maalouf et al., 2001).

Robertson et al. (2003) assessed the cross-modality agreement and inter-observer agreement of computerized tomography and MRI brain imaging for the term or near-term neonate. Subsequently, all 48 neonates had their brain CT and MR images reviewed. The images had to be captured within 72 hours. The results of the study indicated that Ischemic injury is the most common brain abnormality. On conducting McNemar's test, no differences were realized between CT and MR test results. Subsequently, the researchers agreed that there was a presence or absence of abnormality in the CTs and the MRIs. However, in terms of sensitivity, the MRI exhibited a sensitivity of 93.8%, while the CT scan had a sensitivity of 83.3% (Robertson et al., 2003).

Leijser et al. (2007) investigated the role and the range of abnormalities observed in USs and MRI imaging in neonates presenting with metabolic disorders. The images were reviewed with the aim of identifying anatomic and maturation features. The images were also reviewed for cysts, calcium, and other abnormalities. On comparison of the images, 21 USs indicated the presence of oxidative phosphorylation disorders contrary to the 12 observed in the MRIs. 11 USs indicated the presence of ventricular dilation while only 6 MRI images indicated the same. In terms of germinolytic cysts, there were 7 USs and 5 MR images. Similar trends were evident in the detection of germinolytic cysts, abnormal WM, and ventricular dilation. Subsequently, the study concluded that the US images were able to display more abnormalities consistent with neonatal metabolic disorders compared to the MRI images. Consequently, the study reported that while the US exhibited a sensitivity of 91.8% in detecting neonatal metabolic disorders, 84.9 sensitivity was noted in MRI (Leijser et al., 2007).

The objective of Chau et al. (2009) study was to compare the patterns of brain injury in neonatal infants as reflected in CT, conventional MRI, and diffusion-weighted MRI. Specifically, the study targeted newborns suspected of having neonatal encephalopathy. The study's results indicated that MRI and diffusion-weighted MRI had a predominant pattern of injury at 77%. For CT, the diffusion-weighted MRI ability to detect the pattern was found to be 67%. Further, the extent of cortical injury and focal-multifocal lesions, including strokes and WM injury were found to be less apparent on the CT scan compared to diffusion-weighted MRI. For 19 newborns whose repeat MRI was undertaken in the second week of life, the predominant pattern was observed on the third day in diffusion-weighted MRI. Subsequently, the study concluded that diffusion-weighted MRI is the most sensitive technique in assessing brain injury on the third day of life in term newborns with neonatal encephalopathy (Chau et al., 2009).

Intrapiromkul et al. (2013) evaluated the sensitivity and specificity of neonatal brain US in the detection of intracranial hemorrhage in comparison with brain MRI using susceptibility-weighted imaging (SWI). Both the US and MRI scans were evaluated in terms of the ability to evaluate for grade I-III germinal matrix hemorrhage (GMH). Additional observations were anchored on periventricular hemorrhagic infarction (PVHI) and intra-axial hemorrhage. The results indicated that the US had a higher sensitivity of 100%. In terms of specificity, 93.3% was realized. However, the approach had poor sensitivity in the detection of intraventricular hemorrhage. As such, it was determined that SWI is superior to the US in the detection of small intra-axial or extra-axial hemorrhage (Intrapiromkul et al., 2013).

From the literature evaluated, it is evident that although MRI is more sensitive than a CT scan in clinical diagnosis of neonatal brain complications, neonatal brain US is still a better alternative. This is because of studies such as that conducted by Leijser et al. (2007). It is evident that the US reveals detailed aspects of the neonate's brain compared to the MRI. However, a further comparison between the uses of CT scans in neonate brain scans shows that the approach is ineffective in terms of sensitivity and detection of neonate brain-related challenges. These results define the subsequent sections of the current study (Leijser et al., 2007).

The increased uptake of MRI in neonate brain imaging compared to CT scan and the US are based on its comparatively higher accuracy levels. As indicated in the research reviewed in this study, it is evident that both US and CT are equally reliable diagnostic tools in terms of the information they provide. However, in terms of sensitivity and quantification of brain abnormalities, MRI is effective and does not expose infants to radiation (Alkalay et al., 2005). In a similar study conducted by Prager and Roychowdhury (2007), it was realized that the preference for MRI in neonate brain imaging is anchored on the fact that it does not use radiation. The study further discovered that MRIs tend to provide more detailed information about inner organs, which are largely composed of soft tissues. The only fault noted in the use of MRI in neonatal brain scans was its use of strong magnets. However, the author observes that it is unlikely that a neonate would have an implant that would hinder the use of MRI (Prager and Roychowdhury, 2007).

Related results are also reflected in Barnette et al. (2014) study in which the authors observed that brain imaging helps in detecting injuries among neonates and can also be used in predicting long-term outcomes and identification of complications that might require an intervention. The researchers indicated that although MRI is a preferred neonates' brains imaging approach, the US tends to be the most easily accessible diagnostic tool. The study further observed that there are recommendations for all infants born at 31 weeks of gestation to undergo US examination. However, preterm neonates born at 32- and 36 weeks gestation were expected to only have routine US if they were suspected of having developed intracranial haemorrhage or schema. In such cases, brain imaging is done between the fourth and the seventh days post-birth. This is supposed to be succeeded with other imaging episodes between the fourth and the sixth weeks. The expectation was that WM would determine an injury. For comparisons, MRI images were captured at all the stages identified. The results indicated that MRI was more accurate in determining the extent of damage at 96.7% while US attained an accuracy level of 86.3%. These outcomes reflected those attained in other research reviewed in the current study. Subsequently, it was evident that US is comparatively more effective in detecting WM in neonates' brains. These capabilities are also evident in detecting hypoxic-ischemic encephalopathy (HIE) (Barnette et al., 2014). According to Genedi et al. (2016), previously, brain imaging of term infants has involved the use of cranial US and CT. The authors also note that US has been faulted for having several disadvantages in terms of sensitivity, and specificity. Further CT scan has been faulted for making use of radiation. Subsequently, they propose testing the effectiveness of MRI. The authors further observed that in recent years, DWI MRI in the first week of life had been the preferred approach in imaging infants with suspected HIE. Additionally, MR angiography can be used in imaging blood vessels and blood flow in neonates' brains. The other MR imaging approaches include MR venography and arterial spin labeling (ASL). These techniques could be used in detecting additional lesions in infants with HIE. From these observations, it was realized that MRI turns out to be a better approach in neonates' brain imaging (Genedi et al., 2016).

Another study with similar results involved a comparison of US, CT, and MRI in imaging neonate brains. Specifically, the study focused on the detection of intracranial ischemia or haemorrhage. The diagnostic tools were also expected to help determine prognostic values of neuroimaging in neonates suspected of having developed hypoxic-ischemic injury (HII). The study involved forty-seven neonates who were scanned using CT. Of those scanned using MRI twenty-four, while another three were observed using both CT scan and MR imaging. The tests were conducted within the first month of life. Results from the study indicated that CT and MR imaging bore near similar results. For instance, both of them revealed that 25 of the images had HII. Both methods indicated that ten (10) images in both MRI and CT scans indicated that participants had an intraparenchymal hemorrhage. The study concluded that both CT and MR detected HII and GMH more accurately compared to the US. Although the study did not point out the differences between MRI and CT scans, the study reaffirmed their use in neonatal imaging. From the studies analyzed in this section, it is evident that MRI is the most important approach in neonates' brain imaging compared to CT scans and US. The effectiveness of the approach is anchored on the fact that it provides more detailed images leading to accuracy and sensitivity in diagnoses (Barkovich et al., 2006).

### 3.3. Coil technology in MRI and other innovative tools in MRI

The studies indicated that both term and preterm neonates usually require controlled microenvironments and close monitoring when conducting brain MRIs. The purpose of these microenvironments is to ensure that the body maintains its normal respiratory and cardiovascular functions. The body is also expected to maintain its temperature and both fluid and electrolyte homeostasis. Neonates' heads equally tend to be smaller in size, and as such, the use of standard MRI head coils is likely to result in suboptimal picture qualities. In buttressing these observations, Blamire's (2008) studies further argued that the small size of the head prevents the production of high-quality structural and functional MRI. Nevertheless, the innovation of MR compatible incubator with a built-in radiofrequency head coil has come in handy in recent years. The head coil ensures that the neonatal brain volume is optimized (Plaisier et al., 2012; Blamire, 2008; Bekiesińska-Figatowska et al., 2019).

The importance of coil technology is equally reflected in Ahmad et al. (2020) study. The researchers observed that the coil helps insufficient transmission and reception design during MRI imaging. Additionally, the coil technology helped in ensuring that advanced MRI sequences such as the DTI and volumetric acquisitions are highly enhanced. According to Buehrer et al. (2007), this also makes volumetric acquisitions possible to the advantage of neuroradiologists observing neonate MRI brain images. Further, the quality of the images would be more enhanced considering that the head coil transmits and receives RF uniformity that is dependable in spectroscopy. However, the authors note that this approach cannot be compatible with parallel imaging (Buehrer et al., 2007).

Another essential development that has been witnessed in the MRI sector is the creation of smaller scanners that be directly placed in the NICU. In order to achieve this end, a small-bore magnet designed for imaging adult knees has been converted into MRI machines that can scan an infant's whole body. The MRI has an equally strong magnetic field that is consistent with most MR systems. The innovation has been accompanied by specialized patient-handling systems that meet the needs of infants including those born prematurely and sick newborns. According to Tkach et al. (2014), these small-size MRI machines designed for neonates have equally been characterized by a reduction in noise and an improved view of the baby in the scanner. Further, the new MRI machines have been able to support equipment, including ventilators and pumps, which are needed closer to the baby in the process of scanning (Tkach et al., 2012).

Further analyses indicate that currently used scanners tend to have specialized methodologies used in acquisition and processing. This has helped address methodological challenges previously experienced with MRIs' application in neonatal brain scans. The approaches are equally sensitive to motion. Weisenfeld and Warfield's (2009) studies also observed that the current MR sequencing had been adapted to new-borns brains in obtaining relevant soft-tissue contrast. The rationale is that neonatal brain tissues are usually characterized by cerebral structures and incomplete maturation of tissues (Weisenfeld and Warfield, 2009). Invalidating these concerns, Saunders et al. (2007) also remarked that there is a sharp contrast between neonatal and adult brains, making it necessary to explore multiple neurodevelopmental mechanisms precisely. As such, the new inventions in MRI imply that structural changes in the brain that come with age are captured (Saunders et al., 2007). In their study on the applicability of neonatal brain MRI measurements, Gannon et al. (2001) opined that a complex series of dynamic processes should be observable throughout development at both molecular and cellular levels. To achieve this end, current technology has implied that information on brain morphology and structural connectivity is detectable. Equally, the ability of the MRI to scan microstructural properties of grey and white matter and to determine the functional architecture of the neonatal brain has been enhanced considerably. Observably, modern technological advancements have also helped to enhance measures bordering factors such as behavioral and electrophysiological markers (Gannon et al., 2001). According to Blamire (2008), these considerations have helped improve both diagnostic and prognostic perspectives in implementing early interventions. The most notable result is that long-term disability in children has been shelved. From these perspectives, it is evident that MRI is poised even to make future improvements to the advantage of clinical diagnosis of brain-related complications in neonates (Blamire, 2008).

## 4. Conclusion

In conclusion, this study substantiates the pivotal significance of MRI in the domain of neonatal brain imaging when juxtaposed with CT scans and US modalities. The investigation of pertinent literature underscores the historical utilization of both CT scans and US techniques in neonatal brain imaging, with their effectiveness underscored by their precision, specificity, and sensitivity. However, the study also accentuates the transformative influence of technological progress in the sphere of neonatal brain MRI. The integration of novel technologies has notably amplified the safety profile of neonate brain MRI procedures, as observed through the acquisition of precise and secure imaging outputs. These advancements resonate not only with the pursuit of accuracy but also with the paramount consideration of ensuring the well-being and comfort of neonatal subjects. This research underscores the enduring role of MRI as a diagnostic modality in neonatal brain imaging, underscoring its surpassing efficacy in comparison to CT scans and US techniques. It encapsulates the evolution of diagnostic techniques in parallel with technological innovations, fostering a trajectory of improved precision and safety in the investigation of neonatal brain conditions.

## Compliance with ethical standards

### Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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