



The Success of Brain Magnetic Resonance Imaging in Non-Sedated Infants

Na Li Yu, MD¹, Hye Mi Lee, MD², Hyun Gi Kim, MD, PhD³, So-Young Kim, MD, PhD⁴

¹Department of Pediatrics, Chung-Ang University Gwang-Myeong Hospital, Chung-Ang University School of Medicine, Seoul; ²Department of Pediatrics, The Catholic University of Korea, Yeouido St. Mary's Hospital, Seoul; Departments of ³Radiology and ⁴Pediatrics, The Catholic University of Korea, Eunpyeong St. Mary's Hospital, Seoul, Korea

Objective: This study aimed to evaluate the success rate of brain magnetic resonance imaging (MRI) in non-sedated at a single neonatal intensive care unit (NICU).

Methods: Infants underwent brain MRI following a non-sedation protocol during admission to the NICU at The Catholic University of Korea, Eunpyeong St. Mary's Hospital, Seoul, Republic of Korea, from April 2019 to March 2021. All infants underwent brain MRI using the non-sedation protocol, which is immobilizing well-fed infant with vacuum mattress without any sedative medications. "Successful scanning" was defined as completion of scanning with sufficient image acquisition, whereas "scanning failure" was considered when the infant woke up during the course of scanning, resulting in insufficient image acquisition.

Results: A total 175 scans from 172 infants were included. Of these, 102 (59.3%) were male and 107 (62.2%) were born prematurely. The mean birth weight was 2,610 g (range, 810-4,340). The median gestational age at birth was 36.1 weeks (range, 25.7-41). The median postnatal age, postmenstrual age, and body weight of the infants on the day of the scans were 16 days (range, 5-164), 38.4 weeks (range, 35.6-50.7), and 2,959 g (range, 160-5,720), respectively. A total of 167 (95.4%) scans were successfully completed in the first non-sedative trial, whereas the remaining 8 (4.6%) were completed in the second non-sedative trial.

Conclusion: With our high success rate of non-sedation brain MRI, comparable to the procedure with sedatives, many NICUs must adopt this protocol.

Key Words: Brain, Magnetic resonance imaging, Infant, Immobilization

Introduction

Currently, brain magnetic resonance imaging (MRI) is a valuable non-radiation diagnostic tool with high resolution for distinguishing brain lesions. However, it requires a longer time for image acquisition than other modalities such as computed tomography (CT) or ultrasound. For obtaining high image quality, the patient must remain still throughout the scanning, which takes 30 to 40 minutes. As this task can be challenging in neonates, sedatives are used for accurate brain MRI.¹ However, sedatives are associated with an increased risk of adverse reactions, such as desaturation, airway obstruction or vomiting.² Additionally, sedation protocols are complex and time consuming as they involve a pre-sedation assessment, monitoring until recovery, and trained staff for emergency situations.³ The possible harmful effects of repetitive and prolonged use of sedatives on the developing brain in infants have been reported.⁴ Therefore, infant non-sedation protocols, involving

Received: 21 March 2022

Revised: 16 May 2022

Accepted: 19 May 2022

Correspondence to

So-Young Kim, MD, PhD
Department of Pediatrics, The Catholic
University of Korea, Eunpyeong
St. Mary's Hospital, 1021 Tongil-ro,
Eunpyeong-gu, Seoul 03312, Korea
Tel: +82-2-2030-4613
Fax: +82-2-2030-4614
E-mail: sykimped@catholic.ac.kr

Copyright© 2022 The Korean Society of
Perinatology

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided that the original work is properly cited.

feeding and swaddling, have been implemented in many health centers worldwide for painless diagnostic procedures.^{5,6} The previous success rate of MRI with non-sedation protocol in infants were from 87.5% to 94%.⁷⁻¹⁰ The purpose of this study is to evaluate the success rate of brain MRI in infants using a non-sedation technique at our neonatal intensive care unit (NICU).

Methods

1. Subjects

Infants in this study underwent non-enhanced brain MRI using a non-sedation protocol during admission to the NICU at The Catholic University of Korea, Eunpyeong St. Mary's Hospital, Seoul, Republic of Korea between April 2019 and March 2021. The indication for brain MRI was according to the attending physicians. We retrospectively reviewed the success or failure of the examination based on the patients' medical records. The patients' clinical characteristics, including birth weight (BW), gestational age (GA) at birth, postnatal age (PNA), postmenstrual age (PMA), weight at the time of MRI, the main reason for MRI scanning and final diagnosis at NICU discharge were reviewed. This study was approved by the institutional review board (IRB) of The Catholic University of Korea,

Eunpyeong St. Mary's Hospital (IRB no. 2021-1924-0001).

2. Procedures

In the non-sedation protocol, the infant was first fed milk at approximately 30 minutes before the scan. The infant was then gently swaddled on a warm sheet and placed in an incubator to be transported to the MRI suite. A pacifier was made available for the infant in case of awakening during scanning. At the MRI suite, the infant was removed from the transport incubator and moved to a vacuum mattress (Medvac vacuum immobilization bag [MVB]; CFI Medical Solutions, Fenton, MI, USA). Earmuffs (Mini Muffs; Natus Medical Incorporated, San Carlos, CA, USA) were applied to both ears for noise reduction (Fig. 1A). The air inside the MVB was removed by attaching a suction device while maintaining the MVB to tightly fits the infant's body by securing the straps (Fig. 1B). Then, the infant was placed in the MRI scanner with the MVB. An MR-compatible pulse oximeter was placed on the infant's big toe to monitor oxygen saturation and heart rate. In the control room, the physician monitored the infant's vital signs. After completion of the examination, the bag was refilled with air as the MVB was loosened. The infant was placed back into the transport incubator and returned to the NICU.

A "successful scan" was defined as completion of the examination with sufficient image acquisition without the need of



Fig. 1. (A) The swaddled infant was laid in a vacuum mattress with both ears covered with earmuffs. (B) The vacuum mattress became a rigid cradle that tightly fits the infant's body after air was removed through a suction device.

sedative medications. If infants woke up during the scanning, they were taken out of the scan room and soothed. If infants could not be sedated, the pediatric radiologist decided whether to repeat the scan based on the extent and quality of images obtained. If the extent of image acquisition was insufficient, it was defined as “failed scan”. All failed scans were re-scheduled for the following day. Upon repeated failed scan, the physician could choose whether to use sedative medications, such as chloral hydrate (CH) or midazolam.

3. Analysis

Successful scans are shown as a percentage (%) of the total scanning examinations. For the clinical data, we expressed

Table 1. Clinical Characteristics of the Participants

Variable	Value
Sex	
Male	102 (59.3)
Female	70 (40.7)
At birth (n=172)	
GA	36.1 (32.2-40)
≤27 wk 6 day	4 (2.3)
28 wk-33 wk 6 day	30 (17.4)
34 wk-36 wk 6 day	73 (42.4)
≥37 wk	65 (37.8)
BW (g)	2,610±737.5
<1,000	5 (2.9)
1,000-1,499	8 (4.7)
1,500-2,499	63 (36.6)
≥2,500	96 (55.8)
At scanning (n=175)	
PNA (day)	16 (4-28)
≤7	12 (6.9)
8-28	128 (73.1)
≥29	35 (20.0)
PMA (wk)	38.4 (35.5-41.3)
≤36 wk 6 day	13 (7.4)
37 wk-40 wk	115 (65.7)
≥40 wk 1 day	47 (26.9)
BW (g)	2,959 (2,269-3,649)
2,000-2,499	22 (12.6)
2,500-3,999	138 (78.9)
≥4,000	15 (8.6)

qualitative variables as absolute frequencies and percentages. We calculated the mean and standard deviation for normally distributed data; and median and interquartile range (IQR) for data with non-normal distribution. We used IBM SPSS Statistics ver. 28.0 (IBM Corp., Armonk, NY, USA) for statistical analyses.

Table 1. Continued

Variable	Value
The main reason for MRI scanning (n=175)	
Prematurity	70 (40.0)
Respiratory distress that needed mechanical ventilation	38 (21.7)
Clinically suspected asphyxia	24 (13.7)
Seizure	11 (6.3)
Unexplained cardiopulmonary sign ^{a)}	11 (6.3)
Abnormal findings in brain ultrasound	10 (5.7)
Follow-up	3 (1.7)
Skull fracture	2 (1.1)
Poor weight gain	2 (1.1)
Congenital anomaly ^{b)}	1 (0.6)
Hypoglycemia	1 (0.6)
For parents' request	1 (0.6)
Intrauterine growth restriction	1 (0.6)
Final diagnosis at NICU discharge (n=172)	
Respiratory distress syndrome	65 (37.8)
Prematurity	37 (21.5)
Meconium aspiration syndrome	16 (9.3)
Fetal distress	10 (5.8)
Hypoxic-ischemic encephalopathy	7 (4.1)
Neonatal pneumonia	6 (3.5)
Intrauterine growth restriction	4 (2.3)
Neonatal seizure	4 (2.3)
Transient tachypnea of newborn	3 (1.7)
Periventricular leukomalacia	2 (1.2)
Pneumothorax	2 (1.2)
Very low birth weight	2 (1.2)
Others	14 (8.1)

Values are presented as number (%), median (interquartile range), or mean± standard deviation.

GA, gestational age; BW, birth weight; PNA, postnatal age; PMA, postmenstrual age; MRI, magnetic resonance imaging; NICU, neonatal intensive care unit.

^{a)}There were 3 in apnea, 2 each for tachycardia, tachypnea and cyanosis, and 1 for bradycardia and feeding desaturation, respectively. ^{b)}A syndromic baby with single umbilical artery, facial palsy, spinal lipoma and a club foot.

Results

In order to evaluate the success rate of brain MRI in infants using a non-sedation protocol, 175 scans were performed in 172 infants. A total of 172 scans were used to evaluate the infants' neurological status, and 3 scans were repeated in 3 infants for follow-up. The clinical characteristics of the participants are summarized in Table 1. Of 172 infants, 102 (59.3%) were male and 107 (62.2%) were born prematurely. The mean BW was 2,610±737.5 g (range, 810-4,340). The median GA at birth was 36.1 weeks (IQR, 3.9; range, 25.7-41). The median PNA, PMA, and body weight of the infants at the time of the scans were 16 days (IQR, 12; range, 5-164), 38.4 weeks (IQR, 2.9; range, 35.6-50.7), and 2,959 g (IQR, 690; range, 160-5,720), respectively. The main reason for MRI scanning was prematurity (40.0%), respiratory distress that needed mechanical ventilation (21.7%), clinically suspected asphyxia (13.7%), seizure (6.3%), unexplained cardiopulmonary sign (6.3%) and abnormal findings in brain ultrasound (5.7%). The final diagnoses of the included infants at NICU discharge were respiratory distress syndrome (37.8%), prematurity (21.5), meconium aspiration syndrome (9.3%), fetal distress (5.8%) and hypoxic-ischemic encephalopathy (4.1%).

A total of 167 out of 175 scans (95.4%) were successful in the first non-sedative trial, and the remaining 8 (4.6%) were successfully completed in the second non-sedative trial. The demographic findings who failed at first trials summarized in

Table 2. During the scanning, there were no reported clinically significant vital sign changes including oxygen saturation and heart rate. No sedative medications were prescribed as no repeated failed scans were reported with the non-sedation protocol.

Discussion

The development of faster image acquisition, in addition to neonate-compatible MRI incubators and head coils have made MRI an increasingly valuable high resolution diagnostic tool for parenchymal lesions.¹¹ However, for motion limitation during scanning, anesthesia or sedation is often required for children.¹ According to the American Academy of Pediatrics (AAP), sedatives or hypnotics are preferred over analgesic medications during painless diagnostic procedures, such as CT or MRI.³ Among sedative, CH is frequently used in children, with low toxic effects reported in single doses.¹²

The mechanism of CH is not yet completely evaluated, it is assumed that it involves the activation of gamma-aminobutyric acid type A (GABA A) receptors in the central nervous system.¹ According to the 2004 US Food and Drug Administration announcement, repetitive and prolonged use of GABA A receptor agonist may harm the developing brain.⁴ The success rate of MRI with CH-based sedation in young children with CH is satisfactory, but adverse reactions related to sedation

Table 2. The Characteristics of the Patients Who Failed at the First Non-Sedation Trials

No.	1	2	3	4	5	6	7	8
At birth								
GA (wk)	28 wk 2 day	30 wk 1 day	33 wk 4 day	35 wk 6 day	36 wk 0 day	38 wk 6 day	39 wk 3 day	40 wk 4 day
BW (g)	940	1,480	1,660	2,150	2,680	3,720	3,400	3,590
At the scanning								
PNA (day)	115	54	40	13	20	26	11	7
BW (g)	4,270	3,140	2,650	2,330	3,340	4,890	3,550	3,780
Main reason for scanning	Follow-up	Prematurity	Prematurity	Prematurity	Apnea	Follow-up	Respiratory distress that needed MV	Respiratory distress that needed MV
Final diagnosis	RDS	RDS	Prematurity	Prematurity	Prematurity	Neonatal pneumonia	MAS	MAS
Outcome	All succeeded in second non-sedative trial							

GA, gestational age; BW, birth weight; PNA, postnatal age; MV, mechanical ventilation; RDS, respiratory distress syndrome; MAS, meconium aspiration syndrome.

have been reported, including severe respiratory arrest and prolonged respiratory desaturation.¹ For this reason, a trained physician must keep with the patient from the beginning until not only the end of the procedure but also the patient's fully awake, which makes sedation procedures more burdensome to the medical staff. Furthermore, oxyhemoglobin desaturation with CH sedation has been reported to occur more frequently in term infants with younger PNA and younger preterm infants with younger PMA.¹³

The first reported recommendation of using physical restraint, such as cloth, for medical purpose was in 1997 by AAP.¹⁴ Since then, brain MRI in non-sedated, swaddled infants placed in warm sheets has been reported in a number of articles.^{15,16} In line with this, in 2004, the Scottish Intercollegiate Guidelines Network recommended not to use sedatives during painless radiologic procedures in infants up to 4 months of age.¹⁷ In 2005, a study reported that a prematurely born infant at term equivalent age underwent successful brain MRI placed in a vacuum bean bag.¹⁸ The MVB, used in our unit, is an air infusible, chambered bag filled with tiny, evenly distributed beads. If the bag is attached to a pump to evacuate air, the bag will become rigid around the infant. The tightly well-fitted MVB minimizes the subtle movements of the infant during the scanning. After completing the scanning, releasing the valve allows the bag to re-fill with air and loosened. Based on previous successful non-sedation trials, a detailed procedure for brain MRI in non-sedated neonates with immobilizer, including transport and monitoring during scanning was published in 2008.⁶ Since then, many centers have reported the success of non-sedation diagnostic procedures and compared the success rates between non-sedation with immobilizer and sedation conditions.^{7,8,19,20} In the 2008 study by Beauve and Dearlove,²¹ it was reported that the failure rate in non-sedation scanning with immobilizer was not higher than that in CH-sedation scanning. The definite success rates of non-sedation scanning using immobilizer have been reported from 89% to 94%.^{7,8} It is comparable to the success rate in CH sedation scanning which is from 86 to 97.9% according to previous reports.^{2,22,23}

For the domestic study conducted by Yoo et al.¹⁰ in 2021, the success rate of non-sedation brain MRI with immobilizer reported was 87.5%, and the failure rate between sedation

and non-sedation was not statistically different, which is concordant with the results of previous studies. The reason for his slightly lower success rate of non-sedation scanning than that of our study might be that in Yoo's study, only very-low-birth-weight born infants were included. One possible reason for our high successful rate is that our radiologist is very experienced in brain MRI using non-sedation protocol in infants, therefore the MRI technologist might be well educated and skilled with the protocol. For an example, as one person has to hold the infant's body with vacuum bag while the other person suctioning out the air through the attached pump, the bean inside the vacuum bag has to be evenly distributed. When it is unevenly distributed, it might compress any parts of the infant's airway or body, so that it might cause the vital sign changes, which makes the attending medical staff has to re-open the vacuum bag and check the infant, or discomfort to the infant, which makes the infant wakes up in the middle of the scanning. However, the non-sedation protocol itself, as described in the methods, is not a specially trained procedure, so that any non-experienced newly trying centers might easily apply this protocol to the clinics. More studies are needed to evaluate the factors that affect the success of non-sedative, nonpainful diagnostic procedures in infants.

Our study has some limitations. The first non-sedative trial failed group was too small to compare with the first trial success group (8 vs. 167 cases). Further studies, with larger population, comparing the non-sedative failure group from the non-sedative success group would help to identify any associated failing factors such as sex, BW or GA at birth, BW or PNA at the scanning, or patient's underlying diseases. As our unit have started to use non-sedation protocol from the hospital's first opening, we had no sedative group, as for a control group, to compare with the non-sedative group, as for a case group. If any unit is transitioning from sedative to non-sedative imaging or multicenter study, in the similar circumstances with our NICU, comparing the time spent for the scanning or vital sign changes during the scanning between non-sedative and sedative group would help to delineate the effectiveness of the non-sedative procedure.

The strength of our study is that with our reported high success rate in non-sedation protocol, comparable to the sedation used procedures, it is no longer has to use possible

brain harmful sedation medications in infant brain MRI. Also, the medical burden for the sedation procedures, such as long-time vital sign monitoring and side effects of the medication such as desaturation or vomiting might be eased. Many other NICUs must adopt this non-sedation protocol in the infants not only for its own convenience of the procedure but also for the infant's neurodevelopment.

ORCID

Na Li Yu, <https://orcid.org/0000-0003-2851-2991>

Hye Mi Lee, <https://orcid.org/0000-0001-6725-7431>

Hyun Gi Kim, <https://orcid.org/0000-0002-0086-543X>

So-Young Kim, <https://orcid.org/0000-0002-3244-6061>

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Authors' Contributions

Conceptualization: SYK, HGK; Formal analysis: NLY; Investigation: NLY, HML; Visualization: NLY; Writing-original draft: NLY, HML; Writing-review and editing: SYK, HGK, NLY, HML.

References

- 1) Delgado J, Toro R, Rascovsky S, Arango A, Angel GJ, Calvo V, et al. Chloral hydrate in pediatric magnetic resonance imaging: evaluation of a 10-year sedation experience administered by radiologists. *Pediatr Radiol* 2015;45:108-14.
- 2) Malviya S, Voepel-Lewis T, Eldevik OP, Rockwell DT, Wong JH, Tait AR. Sedation and general anaesthesia in children undergoing MRI and CT: adverse events and outcomes. *Br J Anaesth* 2000;84:743-8.
- 3) Coté CJ, Wilson S; American Academy of Pediatrics; American Academy of Pediatric Dentistry. Guidelines for monitoring and management of pediatric patients before, during, and after sedation for diagnostic and therapeutic procedures. *Pediatrics* 2019;143:e20191000.
- 4) US Food and Drug Administration. FDA Drug Safety Communication: FDA review results in new warnings about using general anesthetics and sedation drugs in young children and pregnant women [Internet]. Silver Spring: US Food and Drug Administration; 2016 [updated 2017 Sep 22; cited 2022 May 20]. Available from: <https://www.fda.gov/Drugs/DrugSafety/ucm532356.htm>.
- 5) Prager A, Roychowdhury S. Magnetic resonance imaging of the neonatal brain. *Indian J Pediatr* 2007;74:173-84.
- 6) Mathur AM, Neil JJ, McKinstry RC, Inder TE. Transport, monitoring, and successful brain MR imaging in unsedated neonates. *Pediatr Radiol* 2008;38:260-4.
- 7) Feed-and-sleep: a non-invasive and safe alternative to general anaesthesia when imaging very young children. *J Med Radiat Sci* 2009; 56:5-8.
- 8) Haney B, Reavey D, Atchison L, Poull J, Dryer L, Anderson B, et al. Magnetic resonance imaging studies without sedation in the neonatal intensive care unit: safe and efficient. *J Perinat Neonatal Nurs* 2010;24: 256-66.
- 9) Tsiflikas I, Obermayr F, Werner S, Teufel M, Fuchs J, Schafer JF. Functional magnetic resonance urography in infants: feasibility of a feed-and-sleep technique. *Pediatr Radiol* 2019;49:351-7.
- 10) Yoo YM, Park JE, Park MS, Lee JH. Implementation of the feed and swaddle technique as a non-pharmacological strategy to conduct brain magnetic resonance imaging in very low birth weight infants. *Neonatal Med* 2021;28108-15.
- 11) Tocchio S, Kline-Fath B, Kanal E, Schmithorst VJ, Panigrahy A. MRI evaluation and safety in the developing brain. *Semin Perinatol* 2015;39: 73-104.
- 12) American academy of pediatrics committee on drugs and committee on environmental health: use of chloral hydrate for sedation in children. *Pediatrics* 1993;92:471-3.
- 13) Litman RS, Soin K, Salam A. Chloral hydrate sedation in term and preterm infants: an analysis of efficacy and complications. *Anesth Analg* 2010;110:739-46.
- 14) The use of physical restraint interventions for children and adolescents in the acute care setting. *Pediatrics* 1997;99:497-8.
- 15) Neil JJ, Shiran SI, McKinstry RC, Schefft GL, Snyder AZ, Almli CR, et al. Normal brain in human newborns: apparent diffusion coefficient and diffusion anisotropy measured by using diffusion tensor MR imaging. *Radiology* 1998;209:57-66.
- 16) McKinstry RC, Mathur A, Miller JH, Ozcan A, Snyder AZ, Schefft GL, et al. Radial organization of developing preterm human cerebral cortex revealed by non-invasive water diffusion anisotropy MRI. *Cereb Cortex* 2002;12:1237-43.
- 17) Scottish Intercollegiate Guidelines Network. Safe sedation of children undergoing diagnostic and therapeutic procedures [Internet]. Edinburgh: Scottish Intercollegiate Guidelines Network; 2004 [cited 2022 May 20]. Available from: https://media.gosh.nhs.uk/documents/SIGN_Safe_sedation_of_chierapeutic_procedures.pdf.
- 18) Inder TE, Warfield SK, Wang H, Huppi PS, Volpe JJ. Abnormal cerebral structure is present at term in premature infants. *Pediatrics* 2005;115:

- 286-94.
- 19) Jaimes C, Robson CD, Machado-Rivas F, Yang E, Mahan K, Bixby SD, et al. Success of nonsedated neuroradiologic MRI in children 1-7 years old. *AJR Am J Roentgenol* 2021;216:1370-7.
- 20) Ibrahim T, Few K, Greenwood R, Smith C, Malcolm P, Johnson G, et al. 'Feed and wrap' or sedate and immobilise for neonatal brain MRI? *Arch Dis Child Fetal Neonatal Ed* 2015;100:F465-6.
- 21) Beauce B, Dearlove O. Sedation of children under 4 weeks of age for MRI examination. *Paediatr Anaesth* 2008;18:892-3.
- 22) Bracken J, Heaslip I, Ryan S. Chloral hydrate sedation in radiology: retrospective audit of reduced dose. *Pediatr Radiol* 2012;42:349-54.
- 23) Lee YJ, Kim DK, Kwak YH, Kim HB, Park JH, Jung JH. Analysis of the appropriate age and weight for pediatric patient sedation for magnetic resonance imaging. *Am J Emerg Med* 2012;30:1189-95.