Section: Pediatrics

Original Research Article

ASSOCIATION OF CRANIAL USG FINDINGS WITH INTRAUTERINE GROWTH RESTRICTION (IUGR) IN TERM NEONATES

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ABSTRACT

Background: Fetal Growth Restriction (FGR) is a major contributor to neonatal morbidity and adverse neurodevelopmental outcomes. While extensive research has focused on preterm infants, evidence on cerebral structural and hemodynamic changes in term FGR neonates remains limited. This study aimed to assess cranial ultrasound (CU) abnormalities and middle cerebral artery (MCA) Doppler findings in term FGR neonates compared to appropriate-for-gestational-age (AGA) counterparts.

Materials and Methods: This prospective observational study was conducted over a period of 24 months at a tertiary care neonatal center in Bilaspur, Chhattisgarh. A total of 194 term neonates—97 with FGR and 97 AGA—were enrolled. All neonates underwent cranial ultrasound and MCA Doppler within the first week of life. Structural brain parameters, including cerebellar vermis and transverse cerebellar diameter (TCD), and Doppler flow indices—peak systolic velocity (PSV), end diastolic velocity (EDV), resistive index (RI), and pulsatility index (PI)—were recorded. Statistical analysis was performed using Stata v17.0 with $p < 0.05$ considered statistically significant.

Results: FGR neonates had lower birth weights and higher cesarean delivery rates. Subependymal cysts were significantly more prevalent in FGR neonates (12.4%, $p < 0.0001$). While CU abnormalities were more frequent in FGR neonates (11.3% vs. 2.06%), this did not reach statistical significance ($p = 0.10$). Significant reductions in cerebellar vermis size (2.09 mm vs. 2.3 mm) and TCD (44.8 mm vs. 47.9 mm) were observed in FGR neonates ($p < 0.0001$). Doppler analysis showed reduced EDV and elevated RI in FGR neonates, indicating altered cerebral perfusion.

Conclusion: Term FGR neonates demonstrate early cerebral structural and hemodynamic alterations, supporting the use of CU and MCA Doppler for early risk stratification and surveillance.

Keywords: Fetal growth restriction, Cranial ultrasound, Doppler, Neonatal brain, Cerebellar development.

INTRODUCTION

Fetal growth restriction (FGR) is a condition where a fetus fails to achieve its genetically predetermined growth potential in utero.[1] Affecting 5–10% of pregnancies globally, FGR is a significant contributor to perinatal morbidity and mortality.[2] These infants are at increased risk for complications such as metabolic disturbances, respiratory distress, and long-term neurodevelopmental impairments.[3] Although small for gestational age (SGA), defined as birth weight below the 10th percentile, is often used as a proxy for FGR, the two are not synonymous, and differentiating them remains a clinical challenge.[3]

FGR has been associated with impaired brain development due to chronic hypoxia, placental insufficiency, and nutrient deprivation.[4] These adverse intrauterine conditions can lead to significant structural and functional abnormalities in the developing brain, which may manifest as neurodevelopmental delays. Early identification of such changes is vital for timely intervention.

Cranial ultrasound (CU) serves as a non-invasive, bedside imaging tool to assess neonatal brain structure. It is especially useful for detecting abnormalities like intraventricular hemorrhage (IVH), periventricular leukomalacia, and cerebral atrophy, particularly in neonates at risk due to FGR or SGA status.[5] CU's accessibility and safety make it an important diagnostic modality in neonatal neuroimaging. Several studies have proposed a higher incidence of CU abnormalities (CUAs) among FGR infants, with specific concerns regarding IVH and ischemic changes.[6,7] However, current evidence is inconsistent and often of low certainty.[8]

Furthermore, cerebral artery Doppler studies provide insights into altered cerebral hemodynamics in FGR neonates. Abnormal Doppler results can indicate compromised perfusion, which may not be evident on ultrasound alone.[9] Combining CU with Doppler may enhance diagnostic accuracy in identifying high-risk neonates.

This study aims to explore the association between FGR and CU abnormalities in term neonates. It seeks to bridge the gap in literature that has largely focused on preterm outcomes, thereby improving early detection, optimizing care strategies, and potentially incorporating routine CU screening for term FGR neonates.

MATERIALS AND METHODS

This prospective observational study was conducted in the Department of Radiodiagnosis at Shri Shishu Bhawan Hospital for Children and Newborn, Bilaspur, Chhattisgarh, over a period of 24 months, from July 2023 to June 2025. The study commenced after obtaining approval from the Institutional Ethics Committee. Written informed consent was taken from the guardians of all neonates in their vernacular language before enrollment.

Sample size was calculated based on an expected 20% difference in cranial ultrasound abnormality rates between FGR and non-FGR neonates ($p_1 = 0.6$, $p_2 = 0.4$), with a 95% confidence interval, 80% power, and 5% margin of error. Using a two-tailed z-test for proportions and accounting for a 10% dropout rate, the minimum required sample size was determined to be 97 neonates per group. A total of 194 term neonates were ultimately enrolled.

Inclusion Criteria

- Neonates with gestational age ≥37 weeks
- Diagnosed cases of FGR based on clinical and ultrasonographic parameters
- Term neonates without FGR (AGA) for control group
- Written informed consent obtained from guardians

Exclusion Criteria

- Neonates with congenital anomalies
- Neonates with metabolic disorders
- Multiple gestation (monochorionic diamniotic twins)
- Neonates with known congenital heart disease
- Incomplete clinical data or those not undergoing cranial ultrasound

Methodology

All eligible neonates underwent detailed history-taking and physical examination including anthropometric measurements. Maternal history, antenatal risk factors, mode of delivery, and Apgar scores were documented. Routine investigations were conducted as per NICU protocol. A structured data collection form was used. The form included demographic details, clinical findings, and imaging results. The form was validated by experts and pilot tested. Periodic quality checks were done by the study supervisor.

Study Groups and Allocation

Participants were divided into:

- **FGR Group:** Term neonates with fetal growth restriction
- **AGA Group:** Term neonates appropriate for gestational age

Allocation to groups was done based on consensus between two neonatologists, with blinding to USG findings.

Imaging Procedure: Cranial ultrasound (USG) was performed within the first week of life using a high-frequency (4–8 MHz) linear transducer (GE VIVID .iq USG Machine), with the probe placed over the anterior fontanelle. The following areas were assessed:

- Lateral Ventricles: Assessed for dilation and intraventricular hemorrhage (IVH)
- Periventricular White Matter: Evaluated for echogenicity and periventricular leukomalacia (PVL)
- Cerebellum and Posterior Fossa: Checked for structural abnormalities and hemorrhage
- Cerebral Hemispheres: Screened for cysts, ischemic changes, or structural defects

Doppler ultrasound evaluation was conducted to assess cerebral hemodynamics, with a focus on the middle cerebral artery (MCA), due to its critical role in cerebral perfusion. The MCA was visualized by placing the Doppler transducer over the temporal bone, allowing optimal acquisition of the waveform. The following parameters were measured:

- **Peak Systolic Velocity (PSV):** Maximum blood flow velocity during systole, used to assess compensatory brain-sparing mechanisms.
- **End Diastolic Velocity (EDV):** Velocity during diastole, reflecting downstream vascular resistance.

- **Resistive Index (RI):** Calculated as (PSV − EDV) / PSV. A lower RI suggests vasodilation due to chronic hypoxia in FGR.
- **Pulsatility Index (PI):** Calculated as (PSV − EDV) / Mean Flow Velocity, indicating vascular compliance and resistance.

Abnormal values—notably decreased RI or PI—were interpreted as evidence of altered cerebral perfusion, potentially signifying hypoxic brain injury risk in FGR neonates. All findings were systematically documented in the pre-designed data collection form. All imaging was performed by a consultant radiologist under neonatologist supervision.

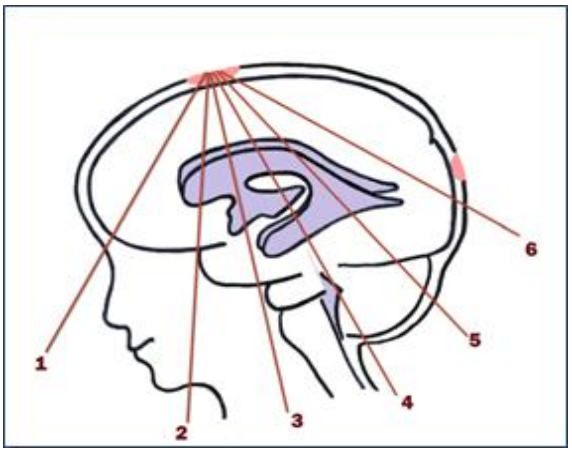

Figure 1. Coronal View of Cranial USG

Observations

- **Primary Outcome:** Incidence of cranial ultrasound abnormalities (IVH, PVL, structural anomalies)
- **Secondary Outcomes:** MCA Doppler findings and 2D brain structure measurements
- Each neonate's CU findings were compared between groups.

Statistical Analysis

Data were entered in Microsoft Excel and analyzed using Stata software version 17.0. Categorical variables were expressed as frequency and percentages, while continuous variables were presented as mean ± SD. Normality was tested using the Kolmogorov–Smirnov and Shapiro–Wilk tests. Chi-square test was used for categorical comparisons, and t-test for continuous variables. Logistic regression was applied to assess the association between FGR and CUAs, adjusting for confounders. A p-value <0.05 was considered statistically significant.

Funding and Conflict of Interest

No external funding was received for the study. All research expenses were borne by the institution and the principal investigator. The authors declare no conflict of interest.

RESULTS

A total of 194 neonates were evaluated, comprising 97 with Fetal Growth Restriction (FGR) and 97 normal neonates. Most FGR neonates (43.3%) were admitted within the first 3 days of life, slightly higher than the normal group (37.1%). Male predominance was observed in both groups, more marked in FGR (73.2% vs. 68%). A clear difference in birth weight was noted, with FGR neonates having a lower mean birth weight (1860 ± 440 g) compared to normal neonates (2810 ± 290 g). Vaginal delivery was less common in FGR cases (60.8%) than in the normal group (81.4%), indicating a higher cesarean section rate among FGR births (39.2%).

Gestational age distribution was similar across groups, though slightly more FGR neonates were delivered at 41 weeks (16.5% vs. 12.4%). Clinically, FGR neonates had a higher incidence of breathing difficulty (19.6% vs. 14.4%), poor feeding (27.8% vs. 17.5%), and delayed cry (9.3% vs. 3.1%), suggesting greater neonatal morbidity and highlighting the need for heightened clinical vigilance in FGR cases. [Table 1]

Table 1: Demographic and Perinatal Characteristics of Neonates with Fetal Growth Restriction Compared to Normal Birth Weight Neonates: A Comparative Analysis

Parameter	Category	FGR (n=97)	%	Normal (n=97)	%
Age at Admission (Days)	0–3	42	43.3%	36	37.1%
	4–7	26	26.8%	28	28.8%
	8–14	23	23.7%	21	21.6%
	≥15	6	6.2%	12	12.4%
Gender	Male	71	73.2%	66	68.0%
	Female	26	26.8%	31	32.0%
Birth Weight	Below Average	62	63.9%	79	81.4%
	Above Average	35	36.1%	18	18.6%
	Mean ± SD (g)	1860 ± 440	—	2810 ± 290	—
Type of Delivery	Vaginal	58	60.8%	79	81.4%
	C-section	38	39.2%	18	18.6%
Gestational Age (Weeks)	37	17	17.5%	25	25.8%
	38	21	21.6%	21	21.6%
	39	24	24.7%	22	22.7%
	40	19	19.6%	17	17.5%
	41	16	16.5%	12	12.4%

Presenting Complaints (YES)	Breathing Difficulty	19	19.6%	14	14.4%
	Poor Feeding	27	27.8%	17	17.5%
	Delayed Cry	9	9.3%	3	3.1%

Out of 194 neonates (97 FGR and 97 normal), antenatal complications such as oligohydramnios (19.6%) and eclampsia (14.4%) were more common in mothers of FGR neonates than in those of normal neonates. Subependymal cysts were exclusively observed in the FGR group (12.4%), which was statistically significant ($p < 0.0001$). Although intraventricular haemorrhage (IVH) and periventricular leukomalacia (PVL) occurred more frequently and with higher severity in FGR neonates, these differences were not statistically significant ($p = 0.280$ and $p = 0.458$, respectively). Sino-venous thrombosis showed no notable variation between the two groups. These findings suggest increased neurological vulnerability in FGR neonates. [Table 2]

Table 2: Antenatal and Cranial Ultrasound Findings in FGR and Normal Neonates

Parameter	Category	FGR (n=97)	%	Normal (n=97)	%	P-value
Antenatal Complications						
Oligohydramnios	Yes	19	19.6%	11	11.3%	—
	No	78	80.4%	86	88.7%	
Eclampsia	Yes	14	14.4%	11	11.3%	—
	No	83	85.6%	86	88.7%	
Subependymal Cysts	Present	12	12.4%	0	0%	< 0.0001
	Absent	85	87.6%	97	100%	
Sino-venous Thrombosis	Present	8	8.25%	7	7.22%	0.78
	Absent	89	91.8%	90	92.8%	
Intraventricular Haemorrhage	Grade I	2	2.06%	2	2.06%	0.280
	Grade II	4	4.12%	1	1.03%	
	Grade III	3	3.09%	1	1.03%	
	Grade IV	2	2.06%	0	0%	
	Absent	86	88.6%	93	96%	
Periventricular Leukomalacia	Grade I	7	7.2%	3	3.09%	0.458
	Grade II	3	3.09%	1	1.03%	
	Grade III	2	2.06%	1	1.03%	
	Grade IV	2	2.06%	1	1.03%	
	Absent	83	85.7%	91	93.8%	

Among the 97 neonates in each group, cranial ultrasound abnormalities were observed in 11.3% (n=11) of FGR neonates compared to 2.06% (n=2) of normal neonates. Although these abnormalities appeared more frequently in the FGR group, the difference did not reach statistical significance ($p = 0.10$), suggesting a possible trend but not a definitive association. [Figure 2]

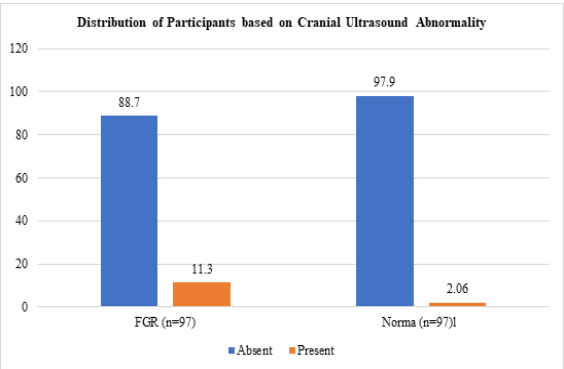

Figure 2: Distribution of Participants based on Cranial Ultrasound Abnormality

Among the intracranial parameters evaluated, significant differences were noted between FGR and normal neonates. FGR neonates had a markedly smaller mean cerebellar vermis size (2.09 ± 0.251 mm) compared to normal neonates (2.3 ± 0.275 mm), with the difference being highly significant ($p < 0.0001$). Likewise, the mean transverse cerebellar diameter was significantly reduced in FGR neonates (44.8 ± 3.95 mm) versus normal neonates (47.9 ± 3.71 mm), also with a p-value < 0.0001. In Doppler assessments of cerebral circulation, the mean peak systolic velocity (PSV) of the middle cerebral artery (MCA) showed no significant difference between the two groups (88.2 ± 3.53 in FGR vs. 89 ± 3.16 in normal neonates, $p = 0.114$). However, the MCA end-diastolic velocity (EDV) was significantly lower in FGR neonates (15.7 ± 4.82) compared to their normal counterparts (24.8 ± 4.42), with a p-value < 0.0001. Additionally, the MCA resistive index (RI) was significantly elevated in the FGR group (0.82 ± 0.053) as opposed to the normal group (0.72 ± 0.047), again with a p-value < 0.0001. The pulsatility index (PI) remained comparable between the groups (1.22 ± 0.179 vs. 1.22 ± 0.176, $p = 0.842$). These results indicate that FGR neonates exhibit both structural and hemodynamic alterations, particularly in the form of reduced brain size and increased vascular resistance. [Figure 3]

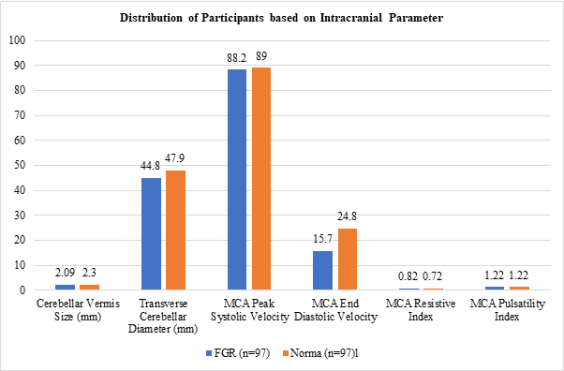

Figure 3: Distribution of Participants based on Intracranial Parameter

DISCUSSION

The present cross-sectional comparative study was conducted in the Level IIIA NICU of Shri Shishu Bhawan Hospital for Children and Newborn, Bilaspur, Chhattisgarh, and involved 194 term neonates—97 with fetal growth restriction (FGR) and 97 appropriate for gestational age (AGA). The aim was to evaluate cranial ultrasound abnormalities (CUAs) and intracranial parameters to understand the impact of intrauterine growth restriction on early brain development.

The present study found a higher prevalence of cranial ultrasound abnormalities (CUAs) in term FGR neonates (11.3%) compared to AGA neonates (2.06%), though not statistically significant (p = 0.10). This suggests increased vulnerability of FGR neonates to early brain injuries, likely due to chronic intrauterine hypoxia and impaired cerebral perfusion. Similar studies, including those by Cruz-Martinez et al,[10] (2015) and Roufaeil et al,[11] (2022) have reported a significantly elevated risk of CUAs in growth-restricted neonates, reinforcing these findings. Additional evidence from MRI-based studies done by Leitner et al. (2007),[12] Tolsa et al,[13] (2004) and Kidokoro et al,[14] (2013) also indicates subtle white and grey matter abnormalities in FGR neonates, even at term. These results underscore the clinical value of routine cranial imaging in term FGR infants to enable early identification and management of potential neurodevelopmental impairments.

In the present study, periventricular leukomalacia (PVL) was more frequently observed in term FGR neonates (14.3%) than in AGA neonates (6.18%), although the difference was not statistically significant (p = 0.458). This trend suggests that FGR may increase susceptibility to periventricular white matter injury even at term. Grade I PVL was most common, but higher-grade lesions (II–IV) were slightly more prevalent in the FGR group. Given PVL's known association with long-term neurodevelopmental issues—such as cerebral palsy and cognitive deficits—these findings are clinically important. Comparable trends were noted in studies like Roufaeil et al,[11] (2022) who found a higher risk of white matter injury in SGA/FGR neonates born after 32 weeks, and Kidokoro et al,[14] (2013) who used MRI to identify subtle but significant white matter abnormalities in term FGR neonates. Long-term imaging and follow-up studies by Tolsa et al,[13] (2004) and Padilla et al,[15] (2011) further highlighted persistent white matter vulnerability and its link to later neurocognitive impairment. Although statistical significance was not achieved, the increased occurrence and severity of PVL in FGR neonates emphasize the importance of routine cranial imaging and ongoing neurodevelopmental surveillance in this high-risk group.

In the present study, intraventricular haemorrhage (IVH) was more common in term FGR neonates (11.34%) compared to AGA neonates (4.12%), though not statistically significant (p = 0.280). Severe grades (III and IV) were notably higher in the FGR group, with no Grade IV cases in controls. This suggests that FGR neonates, even at term, may have increased cerebral vascular fragility and impaired haemodynamic regulation. These findings are supported by Roufaeil et al,[11] (2022) who reported a higher IVH risk in FGR/SGA neonates (RR = 2.40), and Cruz-Martinez et al. (2015),[10] who linked altered fetal Doppler patterns with haemorrhagic lesions. Studies by Beaucourt et al,[16] (1994) and Malhotra et al,[17] (2019) further corroborate that antenatal hypoxia and placental insufficiency in FGR increase IVH susceptibility, reinforcing the need for vigilant neuroimaging and monitoring in this high-risk group.

This study found significant differences in intracranial growth parameters between term FGR and AGA neonates, indicating that intrauterine growth restriction affects brain development even at term. FGR neonates had a significantly smaller cerebellar vermis (2.09 mm vs. 2.3 mm) and transverse cerebellar diameter (44.8 mm vs. 47.9 mm), both with p < 0.0001. These findings suggest impaired midline and lateral cerebellar development in FGR, likely due to chronic hypoxia or nutrient deficiency. Similar studies by Pogliani et al,[18] (2008) and Tolsa et al,[13] (2004) support the role of cerebellar measurements as sensitive markers of intracranial growth disturbances in growth-restricted neonates.

In this study, MCA Doppler analysis revealed no significant difference in peak systolic velocity (PSV) between FGR and AGA neonates (p = 0.114), indicating comparable systolic perfusion. However, FGR neonates showed significantly lower end diastolic velocity (EDV) (15.7 vs. 24.8 cm/s; p < 0.0001) and higher resistive index (RI) (0.82 vs. 0.72; p < 0.0001), reflecting impaired diastolic perfusion and increased cerebrovascular resistance. These findings align with Cruz-Martinez et al,[10] (2015) and Acharya et al,[19] (2005) supporting the concept of disrupted cerebral autoregulation and brain-sparing in FGR.

Further, the MCA resistive index (RI) was significantly higher in FGR neonates (0.82)

compared to AGA neonates (0.72; $p < 0.0001$), indicating reduced cerebral perfusion efficiency, likely due to increased vascular resistance from chronic intrauterine hypoxia. This finding aligns with Acharya et al. (2005),[19] who linked elevated RI with poorer neurodevelopment in growth-restricted infants. However, the MCA pulsatility index (PI) showed no significant difference between groups ($p = 0.842$), suggesting that RI may be a more sensitive marker of diastolic flow impairment in term FGR neonates.

This study compellingly reveals that even among term neonates, fetal growth restriction (FGR) is associated with significant alterations in intracranial development and cerebral perfusion—manifested by reduced cerebellar dimensions and elevated middle cerebral artery resistive indices. These subtle yet critical deviations underscore the profound impact of intrauterine growth compromise on early neurodevelopment, challenging the assumption that term birth ensures neurological normalcy. The findings advocate for the integration of cranial ultrasound and Doppler evaluation as routine surveillance tools in FGR neonates to facilitate early identification and intervention.

While the study's insights are noteworthy, certain limitations must be acknowledged, including its single-centre, cross-sectional design, potential selection bias, interobserver variability, and unaccounted confounding variables. Nonetheless, efforts to reduce bias—such as rigorous inclusion criteria, blinded imaging assessments, and adherence to standardized protocols—strengthen the validity of the results. Future multicentric, longitudinal studies are essential to confirm these associations and to better elucidate the long-term neurodevelopmental trajectory of term FGR infants.

CONCLUSION

In conclusion, the study highlights that term neonates with fetal growth restriction (FGR) exhibit a higher prevalence of neonatal complications, cranial ultrasound abnormalities, and altered cerebral hemodynamics compared to appropriate-for-gestational-age neonates. Although not all differences reached statistical significance, the consistent trends—such as lower birth weight, increased cesarean deliveries, and significantly smaller cerebellar measurements with elevated MCA resistive index—underscore the potential neurodevelopmental risks associated with FGR. These findings advocate for routine cranial ultrasound and close neurological follow-up in FGR neonates, even when born at term.

REFERENCES

1. ACOG Practice Bulletin No. 227: Fetal Growth Restriction. Obstet Gynecol. 2021;137(2):e16–28.
2. Hiersch L, Melamed N. Fetal growth velocity and body proportion in the assessment of growth. Am J Obstet Gynecol. 2018;218(2 Suppl):S700–S711.e1.
3. Lees CC, Romero R, Stampalija T, Dall'Asta A, DeVore GA, Prefumo F, et al. Clinical opinion: The diagnosis and management of suspected fetal growth restriction: An evidence-based approach. Am J Obstet Gynecol. 2022;226(3):366–78.
4. Sacchi C, Marino C, Nosarti C, Vieno A, Visentin S, Simonelli A. Association of intrauterine growth restriction and small for gestational age status with childhood cognitive outcomes: A systematic review and meta-analysis. JAMA Pediatr. 2020;174(8):772–81.
5. Richer EJ, Riedesel EL, Linam LE. Review of neonatal and infant cranial ultrasound. Radiographics [Internet]. 2021 [cited 2024 Oct 10];41(7):E206–7. Available from: https://pubs.rsna.org/doi/10.1148/rg.2021210089
6. de Vries LW, Govaert P. Cranial ultrasound – optimizing utility in the NICU. Curr Pediatr Rev. 2014;10(1):16–27.
7. Malhotra A, Ditchfield M, Fahey MC, Castillo-Melendez M, Allison BJ, Polglase GR, et al. Detection and assessment of brain injury in the growth-restricted fetus and neonate. Pediatr Res [Internet]. 2017 [cited 2024 Oct 10];82(2):184–93. Available from: https://www.nature.com/articles/pr201737
8. Egana-Ugrinovic G, Sanz-Cortes M, Couve-Perez C, Figueras F, Gratacos E. Neurosonographic assessment of the corpus callosum as imaging biomarker of abnormal neurodevelopment in late-onset fetal growth restriction. Fetal Diagn Ther. 2015;37(4):281–8.
9. Aditya I, Somashekhar T, Anitha V, Shankar AM, Mahesh RT, Thomas M. Use of Doppler velocimetry in diagnosis and prognosis of intrauterine growth restriction (IUGR): A review. J Neonatal Perinat Med. 2016;9(2):117–26.
10. Cruz-Martinez R, Figueras F, Arranz A, Botet F, Compte L, Gratacos E. Risk of ultrasound-detected neonatal brain abnormalities in intrauterine growth-restricted fetuses born between 28 and 34 weeks' gestation: relationship with gestational age at birth and fetal Doppler parameters. Ultrasound Obstet Gynecol. 2015;46(4):452–9.
11. Roufaeil LM, Franklin KA, Parkinson CE, Khalil A, Thilaganathan B. Association of fetal growth restriction and small for gestational age status with neonatal cranial ultrasound abnormalities: A systematic review and meta-analysis. BJOG. 2022;129(3):348–57.
12. Leitner Y, Fattal-Valevski A, Geva R, Eshel R, Sira LB, Harel S. Neurodevelopmental outcome of children with intrauterine growth retardation: a longitudinal, 10-year prospective study. J Child Neurol. 2007;22(5):580–7.
13. Tolsa CB, Zimine S, Warfield SK, Freschi M, Sancho Rossignol A, Lazeyras F, et al. Early alteration of structural and functional brain development in premature infants born with intrauterine growth restriction. Pediatr Res. 2004;56(1):132–8.
14. Kidokoro H, Neil JJ, Inder TE. New MR imaging assessment tool to define brain abnormalities in very preterm infants at term. AJNR Am J Neuroradiol. 2013;34(11):2208–14.
15. Padilla N, Alexandrou G, Blennow M, Lagercrantz H, Ådén U. Brain growth gains and losses in extremely preterm infants at term. Cereb Cortex. 2011;21(1):20–7.
16. Beaucourt N, Harrewijn I, Rooman RP, Devlieger H, Casaer P. Perinatal brain injury in growth-retarded infants of 36 weeks gestational age. Eur J Pediatr. 1994;153(3):191–5.
17. Malhotra A, Allison BJ, Castillo-Melendez M, Jenkin G, Polglase GR, Miller SL. Neonatal Morbidities of Fetal Growth Restriction: Pathophysiology and Impact. Front Endocrinol (Lausanne). 2019 Feb 7;10:55. doi: 10.3389/fendo.2019.00055.
18. Pogliani L, Signorini SG, Bastianelli C, Groppo M, Monzani A, Ravasi M, et al. Nomograms for fetal cerebellar vermis length between 18 and 24 weeks of gestation. Prenat Diagn. 2008;28(6):515–8.
19. Acharya G, Wilsgaard T, Berntsen GK, Maltau JM, Kiserud T. Reference ranges for serial measurements of umbilical artery Doppler indices in the second half of pregnancy. Am J Obstet Gynecol. 2005 Mar;192(3):937-44. doi: 10.1016/j.ajog.2004.09.019.