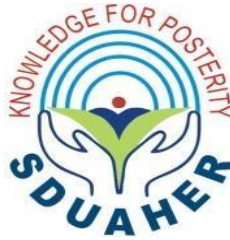


**“ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN
POSTNATAL GROWTH RESTRICTED NEONATES – A CASE
CONTROL STUDY”**

BY

DR. THAVAN MUMMANENI



**DISSERTATION SUBMITTED TO
SRI DEVARAJ URS ACADEMY OF HIGHER EDUCATION &
RESEARCH , TAMAKA, KOLAR, KARNATAKA**

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF MEDICINE

IN

RADIODIAGNOSIS

**UNDER THE GUIDANCE OF
Dr. HARINI BOPAIAH
PROFESSOR
DEPT. OF RADIODIAGNOSIS**

**UNDER THE CO-GUIDANCE OF
Dr. SUDHA REDDY V R,
PROFESSOR & HEAD
DEPT. OF PEDIATRICS**



**DEPARTMENT OF RADIODIAGNOSIS,
SRI DEVARAJ URS MEDICAL COLLEGE
TAMAKA, KOLAR - 563103**

2025

**SRI DEVARAJ URS ACADEMY OF HIGHER EDUCATION AND
RESEARCH, TAMAKA, KOLAR, KARNATAKA**

DECLARATION BY THE CANDIDATE

I hereby declare that this dissertation entitled “**ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN POSTNATAL GROWTH RESTRICTED NEONATES – A CASE CONTROL STUDY**” is a bonafide and genuine research work carried out by me under the guidance of **Dr. HARINI BOPAIAH**, Professor, Department of Radiodiagnosis, Sri Devaraj Urs Medical College, Kolar, and under the co-guidance of **Dr. SUDHA REDDY V R**, Professor & HOD, Department of Pediatrics, Sri Devaraj Urs Medical College, Kolar, in partial fulfillment of University regulation for the award “**M.D. DEGREE IN RADIODIAGNOSIS**”, the examination to be held in 2025 by SDUAHER. This has not been submitted by me previously for the award of any degree or diploma from the university or any other university.

Date:

Place :

Dr. THAVAN MUMMANENI

Postgraduate in Radiodiagnosis

Sri Devaraj Urs Medical

College Tamaka, Kolar.

**SRI DEVARAJ URS ACADEMY OF HIGHER EDUCATION AND
RESEARCH, TAMAKA, KOLAR, KARNATAKA**

CERTIFICATE BY THE GUIDE

This is to certify that the dissertation entitled “**ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN POSTNATAL GROWTH RESTRICTED NEONATES – A CASE CONTROL STUDY**” is a bonafide research work done by **Dr. THAVAN MUMMANENI**, under my direct guidance and supervision at Sri Devaraj Urs Medical College, Kolar, in partial fulfillment of the requirement for the degree of “**M.D. RADIODIAGNOSIS**”.

Date:

Dr. HARINI BOPAIAH MBBS, MD

Place: Kolar

Professor,

Department of Radiodiagnosis

Sri Devaraj Urs Medical College,

Tamaka, Kolar

**SRI DEVARAJ URS ACADEMY OF HIGHER EDUCATION AND
RESEARCH, TAMAKA, KOLAR, KARNATAKA**

CERTIFICATE BY THE CO-GUIDE

This is to certify that the dissertation entitled “**ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN POSTNATAL GROWTH RESTRICTED NEONATES – A CASE CONTROL STUDY**” is a bonafide research work done by **Dr. THAVAN MUMMANENI**, under my co-guidance and supervision at Sri Devaraj Urs Medical College, Kolar, in partial fulfillment of the requirement for the degree of “**M.D. RADIODIAGNOSIS**”.

Date:

Dr. SUDHA REDDY V R MBBS, MD

Place: Kolar

Professor & HOD

Department of Pediatrics,

Sri Devaraj Urs Medical College,

Tamaka, Kolar.

**SRI DEVARAJ URS ACADEMY OF HIGHER EDUCATION AND
RESEARCH, TAMAKA, KOLAR, KARNATAKA**

CERTIFICATE BY THE HEAD OF DEPARTMENT

This is to certify that the dissertation entitled “**ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN POSTNATAL GROWTH RESTRICTED NEONATES – A CASE CONTROL STUDY**” is a bonafide research work done by **Dr. THAVAN MUMMANENI**, under the direct guidance and supervision of **Dr. HARINI BOPAIAH**, Professor, Department of Radiodiagnosis, Sri Devaraj Urs Medical College, Kolar, and under the co-guidance of **Dr. SUDHA REDDY V R**, Professor & HOD, Department of Pediatrics, Sri Devaraj Urs Medical College, Kolar, in partial fulfillment of the requirement for the degree of “**M.D. DEGREE RADIODIAGNOSIS**”.

Date:

Place: Kolar

Dr. ANIL KUMAR SAKALECHA MBBS, MD

Professor & HOD

Department of Radiodiagnosis

Sri Devaraj Urs Medical College Tamaka, Kolar.

**SRI DEVARAJ URS ACADEMY OF HIGHER EDUCATION AND
RESEARCH, TAMAKA, KOLAR, KARNATAKA**

**ENDORSEMENT BY THE HEAD OF THE DEPARTMENT AND
PRINCIPAL**

This is to certify that the dissertation entitled, “**ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN POSTNATAL GROWTH RESTRICTED NEONATES – A CASE CONTROL STUDY**” is a bonafide research work done by **Dr. THAVAN MUMMANENI** under the direct guidance and supervision of **Dr. HARINI BOPAIAH**, Professor, Department of Radiodiagnosis, Sri Devaraj Urs Medical College, Kolar, and under the co-guidance of **Dr. SUDHA REDDY V R**, Professor, Department of Pediatrics, Sri Devaraj Urs Medical College, Kolar, in partial fulfillment of University regulation for the award “**M.D. DEGREE RADIODIAGNOSIS**”.

Dr. ANIL KUMAR SAKALECHA

Professor & HOD

Department of Radiodiagnosis,

Sri Devaraj Urs Medical College,

Tamaka, Kolar.

Date:

Place: Kolar

Dr. PRABHAKAR K

Principal,

Sri Devaraj Urs Medical College

Tamaka, Kolar.

Date:

Place: Kolar

**SRI DEVARAJ URS ACADEMY OF HIGHER EDUCATION AND
RESEARCH, TAMAKA, KOLAR, KARNATAKA**

ETHICAL COMMITTEE CERTIFICATE

This is to certify that the Ethical committee of Sri Devaraj Urs Medical College, Tamaka, Kolar

has unanimously approved

Dr. THAVAN MUMMANENI

Post-Graduate student in the subject of

RADIODIAGNOSIS at Sri Devaraj Urs Medical College, Kolar

to take up the Dissertation work entitled

**“ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN POSTNATAL GROWTH
RESTRICTED NEONATES – A CASE CONTROL STUDY”**

to be submitted to the

**SRI DEVARAJ URS ACADEMY OF HIGHER EDUCATION AND
RESEARCH, TAMAKA, KOLAR, KARNATAKA.**

Signature of Member Secretary

Ethical Committee

Date:

Place: Kolar

Signature of Principal

Dr. PRABHAKAR K

Sri Devaraj Urs Medical College

Tamaka Kolar, Karnataka



SRI DEVARAJ URS ACADEMY OF HIGHER EDUCATION & RESEARCH

SRI DEVARAJ URS MEDICAL COLLEGE

Tamaka, Kolar

INSTITUTIONAL ETHICS COMMITTEE



Members

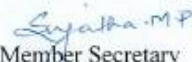
1. Dr. D.E.Gangadhar Rao,
(Chairman) Prof. & HOD of
Zoology, Govt. Women's
College, Kolar
2. Dr. Sujatha.M.P,
(Member Secretary),
Prof. Department of Anesthesia,
SDUMC
3. Mr. Gopinath
Paper Reporter, Samyukth
Karnataka
4. Mr. G. K. Varada Reddy
Advocate, Kolar
5. Dr. Hariprasad S.
Prof. Dept. of Orthopedics,
SDUMC
6. Dr. Abhinandana R
Asst. Prof.
Dept. of Forensic Medicine,
SDUMC
7. Dr. Ruth Sneha Chandrakumar
Assoc. Prof.
Dept. of Psychiatry, SDUMC
8. Dr. Usha G Shenoy,
Asst. Prof., Dept. of Allied
Health & Basic Sciences
SDUAHER
9. Dr. Muniakshmi U
Asst. Prof. Dept. of
Biochemistry, SDUMC
10. Dr. D. Srinivasan,
Assoc. Prof.
Dept. of Surgery,
SDUMC
11. Dr. Shilpa M D
Assoc. Prof.
Dept. of Pathology,
SDUMC

No. DMC/KLR/IEC/55/ 2023-24

Date: 10/04/2023

PRIOR PERMISSION TO START OF STUDY

The Institutional Ethics Committee of Sri Devaraj Urs Medical College, Tamaka, Kolar has examined and unanimously approved the synopsis entitled "**Role Of Middle Cerebral Artery Doppler In Postnatal Growth Restricted Neonates - A Case Control Study**" being investigated by **Dr.Thavan Mummaneni, Dr. Rajeswari & Dr. Sudha Reddy V.R.¹** in the Department of Radio-Diagnosis & Pediatrics¹ at Sri Devaraj Urs Medical College, Tamaka, Kolar. **Permission is granted by the Ethics Committee to start the study.**


Member Secretary
Member Secretary
Institutional Ethics Committee
Sri Devaraj Urs Medical College
Tamaka, Kolar.


Chairman
CHAIRMAN
Institutional Ethics Committee
Sri Devaraj Urs Medical College
Tamaka, Kolar



Sri Devaraj Urs Academy of Higher Education & Research
POST BOX NO.62, TAMAKA, KOLAR-563 101, KARNATAKA, INDIA
Research and Development Cell

Ph:08152-210604, 210605, 243003, 243009, ext. 480, E-mail: dir_research@duaher.ac.in

Central Ethics Committee Re-registered under CDSCO-Registration No. ECR/425/Inst/KA/2013/RR-20 dated 28.4.2020

Ref: SDUAHER/R&D/CEC/SDUMC-PG/38/NF-2025-26 Date: 11-04-2025

Members

- 1. Prof. Dr. S.R Prasad**
Former Professor and
Head, Dept. of Microbiology
SDUMC
- 2. Dr. Bhuvana K**
Professor
Dept. of Pharmacology,
SDUMC
- 3. Dr. Karthik. S**
Assistant Professor
Dept. of Paediatrics
SDUMC
- 4. Dr. G. Vijayalakshmi**
Principal, College of
Nursing, SDUCON
- 5. Mr. Vasudev Moorthy**
Advocate
Shreyas, Kote Mane, Tokal
Road, P.C. Extension Kolar
- 6. Swami**
Dattapadanandaji
Chinmayananda Mission
Institution, Kolar
- 7. Mrs. Veena S,**
Karanjikatte, Kolar
- 8. Dr. Azeem Mohiyuddin**
S.M
Professor and HoD,
Dept. of Otolaryngology,
SDUMC
- 9. Dr. Ashok Kumar. B.S**
Principal,
College of Pharmacy
- 10. Dr. Prabhavathi K**
Professor & HoD,
Dept. of Biochemistry,
SDUMC
- 11. Dr. Sarulatha. H**
Professor, Collage of
Physiotherapy
- 12. Dr. Madhavi Reddy M**
Professor, Department of
Clinical Nutrition and
Dietetics, FAH & BS
- 13. Dr. Venkateswarlu**
Raavi
Assistant Professor,
Dept. of Cell Biology &
Molecular Genetics
FAH & BS
- 14. Ms. Apoorva H.M**
Assistant Professor
Department of Speech
Pathology & Audiology
FAH & BS
- 15. Dr. Kalyani R**
Director
Research and Development
Cell, SDUAHER &
Professor
Dept. of Pathology
SDUMC

PERMISSION FOR CHANGE OF GUIDE

(Ref: No. DMC/KLR/IEC/55/2023-24, Dated: 10-04-2023)

The Central Ethics Committee of Sri Devaraj Urs Academy of Higher Education and Research, Tamaka, Kolar has examined and approved the Change of Guide for post graduate research proposal entitled: **“Role of Middle Cerebral Artery Doppler in postnatal Growth Restricted Neonates – A Case Control Study”**.

This study is carried out by **Dr. Thavan Mummaneni, Dr. Rajeswari, and Dr. Sudha Reddy, V. R** in the Departments of Radio- Diagnosis and Pediatrics at Sri Devaraj Urs Medical College, and SDUAHER Tamaka, Kolar.

Permission is granted for Change of Guide from **Dr. Rajeswari, (Current Guide)** to **Dr. Harini Bopaiah, Professor (Newly Assigned Guide)** Department of Radio-Diagnosis, SDUMC.

Copy to:

1. Member Secretary
Scientific Review Committee
SDUMC
2. **Dr. Thavan Mummaneni**
Junior Resident
Dept. of Radio- Diagnosis
SDUMC

Dr. Kalyani R
Member Secretary
Central Ethics Committee
Prof. Dr. Kalyani. R.
Member Secretary
Central Ethics Committee
Research and Development Cell
SDUAHER

**SRI DEVARAJ URS ACADEMY OF HIGHER EDUCATION AND
RESEARCH, TAMAKA, KOLAR, KARNATAKA**

COPY RIGHT DECLARATION BY THE CANDIDATE

I hereby declare that Sri Devaraj Urs Academy of Higher Education and Research, Kolar, Karnataka shall have the rights to preserve, use and disseminate this dissertation / thesis in print or electronic format for academic/research purpose.

Date:

Place: Kolar

Dr. THAVAN MUMMANENI

Post graduate

Department of Radiodiagnosis

Sri Devaraj Urs Medical College

Tamaka, Kolar

ACKNOWLEDGEMENT

*I owe debt and gratitude to my parents **M. RANGARAO** and **M. R.C. Kumari** for their moral support and constant encouragement during the study. I owe my gratitude to my spouse **Dr. B. SATYA** for her support.*

*With humble gratitude and great respect, I would like to thank my teacher, mentor and guide, **Dr. HARINI BOPAIAH**, Professor, Department of Radiodiagnosis, Sri Devaraj Urs Medical College, Kolar, for his able guidance, constant encouragement, immense help and valuable advices which went a long way in molding and enabling me to complete this work successfully. Without her initiative and constant encouragement this study would not have been possible. Her vast experience, knowledge, able supervision and valuable advices have served as a constant source of inspiration during the entire course of my study.*

*I would like to express my sincere thanks and humble gratitude to **Dr. ANIL KUMAR SAKALECHA**, Professor & H.O.D., Department of Radiology, Sri Devaraj Urs Medical College, Kolar, for his guidance, constant encouragement, immense help and valuable advices.*

*I would like to express my sincere thanks and humble gratitude to my initial guide and mentor **Dr. RAJESWARI**, Ex Associate Professor, Department of Radiology, Sri Devaraj Urs Medical College, Kolar, and **Dr. SUDHA REDDY V R**, Professor & H.O.D., Department of Pediatrics, Sri Devaraj Urs Medical College, Kolar, for their guidance, constant encouragement, immense help and valuable advices.*

I would also like to thank the Assistant Professor's "Dr. HEMANTH G S, Dr. JAGANNATHAN, Dr. USHA, Dr. MAHIMA KALE & Dr. BHARGAVI", Department of Radiodiagnosis, Dr. GURU YOGENDRA, Dr. SURYA KANTH, Dr. SIVA SIDDANTH, Dr. KRISHNA, Dr. RISHI PRAJWAL, Dr. GAURAV, Dr. JAYENDRA MANNAN, Dr. SHANTALA & Dr. POOJITHA and all my teachers, Department of Radiodiagnosis, Sri Devaraj Urs Medical College for their wholehearted support and guidance.

I am extremely grateful to the patients who volunteered for this study, without them this study would just be a dream.

I am thankful to my fellow postgraduates Dr. VAMSI VENKAT, Dr. VIMAL, Dr. NISHANTH, Dr. SOUMYA, Dr. SRAVYA, Dr. SAMEER, Dr. PRIYANKA, Dr. NEELAM, Dr. JEET, Dr. HARSHINI, Dr. VAIBHAV, Dr. SUPRITH, Dr. SUHAS, Dr. SNEHA, Dr. RASHMI, Dr. NAINI and Dr. KUSH for having rendered all their co-operation and help to me during my study.

My sincere thanks to Mr. AMARESH, Mrs. NASEEBA, Mrs. HAMSA, Mrs. RADHA, Mr. RAVI, Mr. SUBRAMANI and rest of the Non-teaching staff and computer operators, staff nurses and other technicians of Department of Radiodiagnosis, R.L Jalappa Hospital & Research Centre, Tamaka, Kolar for their help.

Dr. THAVAN MUMMANENI

Post graduate,

Department of Radiodiagnosis.



SRI DEVARAJ URS ACADEMY OF HIGHER EDUCATION & RESEARCH
TAMAKA, KOLAR, KARNATAKA, INDIA 563103

CERTIFICATE OF PLAGIARISM CHECK

Title of the Thesis/Dissertation	ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN POSTNATAL GROWTH RESTRICTED NEONATES – A CASE CONTROL STUDY
Name of the Student	DR. THAVAN MUMMANENI
Registration Number	22RD1052
Name of the Supervisor / Guide	DR. HARINI BOPAIAH
Department	RADIODIAGNOSIS
Acceptable Maximum Limit (%) of Similarity (PG Dissertation /Ph.D. Thesis)	10 %
Similarity	09%
Software used	TURNITIN
Paper ID	2671973831
ORCID ID	0009-0005-2207-032X
Submission Date	10/05/2025

M. Thavan

Signature of Student

Harini Bopai

Signature of Guide/Supervisor

Professor
Dept. of Radio-Diagnosis
R.L.J. Hospital & Research Centre
Tamaka, Kolar-563 101

Harini Bopai

HOD Signature

Prof. & HOD

Dept. of Radiodiagnosis
Sri Devaraj Urs Medical College
Tamaka, Kolar-563101.

10/5/25

University Librarian
University Library
Learning Resource Centre
SDUAHER, Tamaka
KOLAR-563103

12/5/2025

PG Coordinator

PG Coordinator
Sri Devaraj Urs Medical College
Tamaka, Kolar-563103



Digital Receipt

This receipt acknowledges that Turnitin received your paper. Below you will find the receipt information regarding your submission.

The first page of your submissions is displayed below.

Submission author: DR. THAVAN MUMMANENI
Assignment title: PG Dissertation - 2025
Submission title: ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN POSTNATAL ...
File name: OSTNATAL_GROWTH_RESTRICTED_NEONATES_A_CASE_CONTR...
File size: 4.17M
Page count: 58
Word count: 10,760
Character count: 60,210
Submission date: 10-May-2025 12:31PM (UTC+0530)
Submission ID: 2671973831

“ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN POSTNATAL GROWTH RESTRICTED-NEONATES – A CASE CONTROL STUDY”

ABSTRACT

Introduction


Fetal Growth Restriction (FGR) constitutes a significant obstetric complication with well-documented associations with neonatal morbidity, mortality, and long-term neurodevelopmental impairments. Alterations in cerebral hemodynamics, particularly within the middle cerebral artery (MCA), may reflect adaptive mechanisms and serve as early indicators of neurological compromise. Despite advancements in prenatal imaging, the prognostic value of postnatal cerebral Doppler indices in FGR neonates remains inadequately explored.

Aim & Objectives

To compare middle cerebral artery (MCA) Doppler characteristics between term growth-restricted (FGR) and gestational age-matched neonates. To evaluate the prognostic value of MCA Doppler parameters for early neurological outcomes and to assess the association between MCA Doppler findings and cerebral MRI findings in FGR neonates. To determine whether reversal of blood flow in MCA serves as a marker of morbidity and neurological morbidity.

Methods

A prospective, case-control observational study was conducted over an 18-month period in a tertiary academic hospital, enrolling 86 neonates (48 FGR and 48 AGU). Cerebral ultrasonography with MCA Doppler evaluation was performed on neonatal days 1, 3, 7, and 14 using a standardized methodology approach. Doppler indices were analyzed and correlated with neurological outcomes and MRI outcomes. Statistical analysis included


University Library
Learning Resource Centre
SDUAHER, Tamaka
KOLAR-563103


Professor
Dept. of Radio-Diagnosis
R.L.J. Hospital & Research Centre
Tamaka, Kolar-563 101

Turnitin Originality Report

Document Viewer

Processed on: 16-May-2025 12:32:57
ID: 2671973811
Word Count: 10760
Submitted: 1

Similarity Index	Similarity by Source
9%	Internet Sources: 7% Publications: 7% Student Papers: 2%

ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN POS... By DR. THAVAN MUMMANENI

include quoted include bibliography excluding matches < 10 words mode: quickview (classic) report print refresh

download

- 1% match (Internet from 16-Aug-2021)
https://www.iss-so.com/uploads/2/0/1/5/201533210/iss_dec_20_combined.pdf
- <1% match (Internet from 16-Oct-2021)
https://link.springer.com/content/pdf/10.1007/978-3-319-77815-0.pdf?code=89305849-5rd3-4b6b-a787-14e9901f6b8&error=cookies_not_supported
- <1% match (Internet from 03-Nov-2021)
https://link.springer.com/article/10.1007/s00631-019-03540-3?code=17c2908b-dd86-4326-8e87-85fd0317695&error=cookies_not_supported
- <1% match (Internet from 19-Mar-2025)
<https://www.frontiersin.org/research-topics/7299/erub>
- <1% match (Internet from 12-Mar-2025)
<https://www.frontiersin.org/research-topics/60207/erub>
- <1% match (Internet from 15-Jun-2023)
<https://www.frontiersin.org/articles/10.3389/fneur.2023.1135406/full>
- <1% match (student papers from 29-Apr-2025)
Submitted to Sri Devaraj Urs Academy of Higher Education and Research, Kolar on 2025-04-29
- <1% match ("Doppler Ultrasound in Obstetrics and Gynecology", Springer Science and Business Media LLC, 2023)
"Doppler Ultrasound in Obstetrics and Gynecology", Springer Science and Business Media LLC, 2023
- <1% match (Akhil Maheshwari, Jyoti Patodia, Pradeep Suryawanshi, Gunjana Kumar, Nirmal Chandra Padhan, "Transcranial Doppler: A New Stethoscope-Voiceover Tool for Neonatal Brain", Newborn, 2024)
Akhil Maheshwari, Jyoti Patodia, Pradeep Suryawanshi, Gunjana Kumar, Nirmal Chandra Padhan, "Transcranial Doppler: A New Stethoscope-Voiceover Tool for Neonatal Brain", Newborn, 2024
- <1% match (Internet from 14-Jan-2023)
<https://www.mdpi.com/2072-6651/13/2/85/html>
- <1% match (Internet from 14-Dec-2024)
<https://www.mdpi.com/2076-2615/14/23/3350>
- <1% match (Internet from 15-Apr-2025)
<https://journal.barristaags.co.in/pdf/10423.pdf>
- <1% match (Internet from 15-Sep-2023)
<https://www.isakos.com/Asspts/Meetings/2023Congress/Manuscripts/Ramakanth-Manuscript.pdf>
- <1% match (Internet from 12-Feb-2023)
https://www.researchgate.net/publication/261187714_Doppler_velocimetric_parameters_of_the_testicular_artery_in_healthy_dogs
- <1% match (Internet from 30-Jun-2022)
https://www.researchgate.net/publication/335082971_Pro prospective_validation_of_a_novel_visual_analogue_uroflowmetry_score_VAUS_in_men
- <1% match (Soni, Surabhi, "Measurement of Fetal Transcerebellar Diameter for Estimation of Gestational Age in Intrauterine Growth Restriction Cases", Rajiv Gandhi University of Health Sciences (India), 2023)
Soni, Surabhi, "Measurement of Fetal Transcerebellar Diameter for Estimation of Gestational Age in Intrauterine Growth Restriction Cases", Rajiv Gandhi University of Health Sciences (India), 2023
- <1% match (H.-C. Fu, "Comparison of clinical outcomes and spectral Doppler indices of uterine and ovarian stromal arteries in women undergoing myomectomy with or without hypogastric arterial ligation", Ultrasound in Obstetrics and Gynecology, 11/2006)
H.-C. Fu, "Comparison of clinical outcomes and spectral Doppler indices of uterine and ovarian stromal arteries in women undergoing myomectomy with or without hypogastric arterial ligation", Ultrasound in Obstetrics and Gynecology, 11/2006
- <1% match (Internet from 12-May-2023)
<http://maastfactor.org>
- <1% match (Internet from 03-Sep-2020)
<https://journals.sagepub.com/doi/full/10.4137/CMPed.540073>
- <1% match (Internet from 19-Nov-2016)

Professor
Dept. of Radio-Diagnosis
R.L.J. Hospital & Research Centre
Tamaka, Kolar-563 101

University Library
Learning Resource Centre
SDAHER, Tamaka
KOLAR-563103

https://test.usrds.org/2013/04/02_00_preds_12.pdf

<1% match (Internet from 06-May-2025)

<https://library.uerm.edu.ph/kahalmagca/JEBM/repository/Online%20Resources/II-Bpocs/9781315152950.pdf>

<1% match (Internet from 16-May-2021)

<https://www.jcocho.org/article.asp?ajournal=O%27Andrea&page=41&issn=2211-4122&issue=28&page=288&volume=76&year=2015>

<1% match (Internet from 16-Nov-2023)

<https://jgurgmed.com/issue/download/360/332>

<1% match (Internet from 31-Mar-2022)

<https://stm.bookipr.org/IDMMR-V10/article/view/5834>

<1% match (Internet from 25-Oct-2022)

<https://repositorio.una.ac.cr/bitstream/handle/11056/23051/Estimaci%C3%B3n+Nacional%20de%20AGOSTO%29%20de%20n%C3%B3rdica%29.pdf?isAllowed=y&sequence=1>

<1% match (Niki Oikonomopoulou, Maria Jose Rodriguez-Castaño, Araceli Corredera, Cristina Cortés-Ledesma et al. "Extremely preterm infants with adverse neurological outcome present more frequently impaired right ventricular performance", *Pediatric Research*, 2025)

Niki Oikonomopoulou, Maria Jose Rodriguez-Castaño, Araceli Corredera, Cristina Cortés-Ledesma et al. "Extremely preterm infants with adverse neurological outcome present more frequently impaired right ventricular performance", *Pediatric Research*, 2025

<1% match (Internet from 04-Apr-2023)

<https://www.ncbi.nlm.nih.gov/books/NBK562268/?report=reader>

<1% match (Wilhelm Schäberle. "Ultrasonography in Vascular Diagnosis", Springer Science and Business Media LLC, 2018)
Wilhelm Schäberle. "Ultrasonography in Vascular Diagnosis". Springer Science and Business Media LLC, 2018

<1% match (Internet from 19-Mar-2023)

<https://medicalresearchjournal.org/index.php/GJMR/issue/download/453/367>

<1% match (Joseph Donovan, Anthony Figaji, Darma Imran, Nguyen Hoan Phu, Ursula Rohlwick, Guy E Thwaites. "The neurocritical care of tuberculous meningitis", *The Lancet Neurology*, 2019)
Joseph Donovan, Anthony Figaji, Darma Imran, Nguyen Hoan Phu, Ursula Rohlwick, Guy E Thwaites. "The neurocritical care of tuberculous meningitis", *The Lancet Neurology*, 2019

<1% match (Vitošević, Filip Z.. "Ispitivanje Uticaja Morfoloških Karakteristika Intrakranijalnih Aneurizmi u Proceni Rizika od Rupture Primenom Trodimenzionalne Digitalne Suptrakcione Angiografije", University of Belgrade (Serbia), 2024)
Vitošević, Filip Z.. "Ispitivanje Uticaja Morfoloških Karakteristika Intrakranijalnih Aneurizmi u Proceni Rizika od Rupture Primenom Trodimenzionalne Digitalne Suptrakcione Angiografije", University of Belgrade (Serbia), 2024

<1% match (Internet from 18-Oct-2020)

<https://educationasia.in/neet-up/answer-key>

<1% match (Internet from 11-Nov-2024)

https://ia804603.us.archive.org/5/items/emergency_medicine_books/Echocardiography%20-%20Books/Echo%20Made%20Easy%20-%20Third%20Edition%20-%202012.pdf

<1% match (Internet from 29-Dec-2024)

<https://pubmed.ncbi.nlm.nih.gov/articles/PMC9580132/>

<1% match (Submitted to Sveučilište Jurja Dobrile u Puli / Juraj Dobrile University of Pula)
Submitted to Sveučilište Jurja Dobrile u Puli / Juraj Dobrile University of Pula

<1% match (Internet from 28-Nov-2024)

<https://euraseans.com/index.php/journal/issue/download/49/issue%204%2847%29>

<1% match (Internet from 12-Mar-2022)

<https://www.science.gov/topicpages/f/females+gestational+age>

<1% match (Internet from 28-Jun-2022)

<https://www.sciencegate.app/document/10.11157/mu-1901>

<1% match (D., Chaitra. "Comparison of Clinical Assessment of Nutritional Status Score with Other Methods in the Assessment of Fetal Malnutrition", Rajiv Gandhi University of Health Sciences (India), 2023)
D., Chaitra. "Comparison of Clinical Assessment of Nutritional Status Score with Other Methods in the Assessment of Fetal Malnutrition", Rajiv Gandhi University of Health Sciences (India), 2023


<1% match (Eric S. Peeples, Chikodinaka K. Ezeokeke, Sandra E. Juul, Pierre D. Mourad. "Evaluating a Targeted Bedside Measure of Cerebral Perfusion in a Nonhuman Primate Model of Neonatal Hypoxic-Ischemic Encephalopathy", *Journal of Ultrasound in Medicine*, 2018)

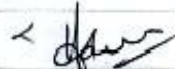
Eric S. Peeples, Chikodinaka K. Ezeokeke, Sandra E. Juul, Pierre D. Mourad. "Evaluating a Targeted Bedside Measure of Cerebral Perfusion in a Nonhuman Primate Model of Neonatal Hypoxic-Ischemic Encephalopathy", *Journal of Ultrasound in Medicine*, 2018

<1% match (Swathi Surapaneni. "Comparative Study of Transcervical Foley Catheter Versus 50 µg Intravaginal Misoprostol for Induction of Labor", *Indian Journal of Obstetrics and Gynecology*, 2016)

Swathi Surapaneni. "Comparative Study of Transcervical Foley Catheter Versus 50 µg Intravaginal Misoprostol for Induction of Labor", *Indian Journal of Obstetrics and Gynecology*, 2016

<1% match (Internet from 04-Jan-2025)


University Library
Learning Resource Centre
SDUAHER, Tamaka
KOLAR-563103


Professor
Dept. of Radio-Diagnosis
R.L.J. Hospital & Research Centre
Tamaka, Kolar-563 104

<https://ajmi.journals.ekb.eg/article/159455.html>

<1% match (Internet from 23-Dec-2024)

<https://hmceregna.ucth@birth.biomedcentral.com/articles/10.1186/s12884-024-06621-w>

<1% match (Internet from 12-Dec-2022)

<https://eur.medrxiv.org/content/10.1101/2022.12.01.202001-018-0305-1.pdf>

"ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN POSTNATAL GROWTH RESTRICTED NEONATES – A CASE CONTROL STUDY." ABSTRACT Introduction Fetal Growth Restriction (FGR) constitutes a significant obstetric complication with well-documented associations with neonatal morbidity, mortality, and long-term neurodevelopmental impairment. Alterations in cerebral hemodynamics, particularly within the middle cerebral artery (MCA), may reflect adaptive brain-sparing responses and serve as early indicators of neurological compromise. Despite advancements in perinatal imaging, the prognostic value of postnatal cerebral Doppler indices in FGR neonates remains inadequately explored. Aim & Objectives: To compare middle cerebral artery (MCA) Doppler characteristics between fetal growth-restricted (FGR) and gestational age-matched neonates. To evaluate the prognostic value of MCA Doppler parameters for early neurological outcomes and to assess the association between MCA Doppler findings and prolonged NICU stay in FGR neonates. To determine whether reversal of diastolic flow in MCA serves as a marker of mortality and neurological morbidity. Methods: A prospective, case-control observational study was conducted over an 18-month period at a tertiary academic center, enrolling 96 neonates (48 FGR and 48 AGA). Cranial ultrasonography with MCA Doppler evaluation was performed on postnatal days 1, 3, 7, and at 1 month using a standardized transtemporal approach. Doppler indices were analyzed and correlated with neurological outcomes and NICU duration. Statistical analyses included Mann-Whitney U, chi-square, Kruskal-Wallis tests, and receiver operating characteristic (ROC) curve analysis. Results: At 1 month, FGR neonates exhibited significantly elevated MCA PSV (43.10 cm/s vs. 39.90 cm/s, $p < 0.05$). Among all parameters, EDV demonstrated the highest predictive validity for unfavorable neurological outcomes, with an area under the ROC curve (AUC) reaching 0.76 and odds ratios ranging from 1.20 to 1.30 ($p < 0.01$). While PI and RI exhibited high specificity, their sensitivity and AUC values were suboptimal. Lower PI and RI were significantly associated with extended NICU admissions and adverse neurological sequelae, such as periventricular leukomalacia and convulsions. Reversal of end-diastolic flow in MCA was observed exclusively in two FGR neonates who subsequently expired. Conclusion: Postnatal MCA Doppler assessment, particularly EDV, offers meaningful prognostic insight into early neurological outcomes in neonates with FGR. Routine serial evaluation of cerebral hemodynamics may facilitate timely risk stratification and clinical intervention. Further multicentric investigations with longitudinal follow-up are warranted to corroborate these findings and enhance their clinical applicability. Keywords: Fetal Growth Restriction (FGR), Middle Cerebral Artery (MCA), End-Diastolic Velocity (EDV), Resistive Index (RI), Pulsatility Index (PI). 1. INTRODUCTION Fetal Growth Restriction (FGR) is a prevalent pregnancy complication characterized by a fetus not achieving its genetically predetermined growth potential, primarily due to pathological factors like placental dysfunction. This condition is the second most cause of perinatal morbidity and mortality, which also predispose to poorer neurodevelopmental outcomes. 1,2 FGR infants are at risk for neonatal complications like asphyxia, hypothermia, hypoglycemia, and polycythemia, with potential long-term effects including growth retardation and neurodevelopmental disorders. Impaired oxygen and nutrient delivery to the fetal brain, compounded by oxidative stress and neuroinflammation, may predispose FGR neonates to neurologic outcomes such as cerebral palsy, cognitive and learning impairments, and structural deficits in gray and white matter. 1,3 Neurosonography is a vital, non-invasive imaging technique used to assess the neonatal brain, particularly in the early postnatal period. The portability, safety, and accessibility of neurosonography make it an ideal first-line tool in neonatal intensive care units for bedside evaluation of intracranial structures without the need for sedation or exposure to ionizing radiation. 4 Its primary applications include the detection and monitoring of conditions such as transient periventricular echodensities (TPE), germinal matrix hemorrhage (GMH), intraventricular hemorrhage (IVH), periventricular leukomalacia (PVL), hydrocephalus, and other structural or ischemic brain injuries—conditions more frequently encountered in growth-restricted and preterm neonates. 5 Recent advancements in high-frequency transducers, Doppler modalities, and standardized imaging protocols have significantly enhanced its diagnostic accuracy and anatomical detail in assessing cerebral structural and hemodynamic changes in neonates, especially those at risk of neurological compromise. 4,5 In the context of FGR fetuses, blood flow is redistributed to prioritize the brain, heart, and adrenal glands over the gut which persist in the early perinatal period of neonate. These alterations in cerebral blood flow reflect an adaptive response to hypoxia, commonly referred to as the "brain-sparing effect." 6 FGR abnormalities, like TPE, PVL, and IVH are associated with cerebrovascular alterations in the early perinatal period which can be assessed in neurosonography. Therefore, identifying predictors of adverse outcomes in FGR is critical for the optimal management of high-risk pregnancies and affected neonates. Neurosonography along with postnatal Doppler ultrasound of the cerebral arteries, can provide valuable cerebrovascular parameters. 7,8 Doppler ultrasound of the MCA allows real-time assessment of cerebral hemodynamics by measuring parameters such as Resistive Index (RI), Pulsatility Index (PI), and Peak Systolic Velocity (PSV). Middle Cerebral Artery (MCA) Doppler accuracy may vary based on the operator technique and anatomical site of measurement and is less likely affected by the angle of insonation. 5 A recent systematic review concluded that RI lacks sufficient evidence for routine monitoring in preterm infants. However, it may still hold diagnostic value in neonates with hypoxic-ischemic encephalopathy (HIE) and other early neurological manifestations. 9,10 Many studies have examined the relationship between altered pulsatility index and peak systolic velocity in fetal cerebral arteries and perinatal outcomes. However, there is a lack of research on postnatal cerebral blood flow characteristics and their impact on term neurodevelopment in FGR infants. 11 This study aims to compare the postnatal middle cerebral artery Doppler characteristics in neonates with fetal growth restriction to those of gestational age-matched controls. 2. AIMS AND OBJECTIVES Aim 1. To assess and compare the middle cerebral artery Doppler characteristics between fetal growth restricted neonates and gestational age-matched neonates. Other Objectives 2. To evaluate the prognostic value of MCA Doppler parameters for early neurological outcomes in neonates and to assess the association between MCA Doppler findings and prolonged NICU stay in FGR neonates. 3. To determine whether reversal of diastolic flow in MCA serves as a marker of mortality and neurological morbidity. 3. REVIEW OF LITERATURE 3.1 DOPPLER ULTRASOUND Sound Waves and Their Properties "Ultrasound is a mechanical wave transmitted through a medium by molecular vibrations. These vibrations propagate in a sinusoidal pattern, causing compressions and rarefactions in the medium. The key characteristics of sound waves include: Frequency (f): Measured in hertz (Hz), it denotes cycles per second. Wavelength (λ): The distance between two points of maximum compression. Propagation speed (c): The speed at which the wave moves through tissue, approximately 1540 m/s in soft tissue. The relationship is defined by the equation: $c = \lambda \times f$ Diagnostic ultrasound typically uses frequencies between 2–30 MHz's whereas, wavelengths used in transcranial ultrasonography is around the lower range of spectrum around 2 MHz". 5,12 Principles of Doppler Ultrasound "The Doppler effect also known as the Doppler shift is first described by Christian Doppler in 1842, refers to the change in frequency of a wave caused by the relative motion between the source and the observer. Doppler shift is influenced by the moving source's velocity and direction relative to the reflector, resulting in a frequency change between the source and receiver as described in figure 1. A common example of this is the changing pitch of an ambulance siren as it moves past an observer. In medical ultrasound, the Doppler effect is utilized to assess blood flow. As red blood cells move, they reflect ultrasound waves at different frequencies depending on their velocity and direction in relation to the transducer". 5,12 Figure 1. Doppler shift effect "The Doppler frequency shift (Fd) is calculated using the Doppler equation: $F_d = (2 \times F_e \times v \times \cos \theta) / c$ Where: F_d = Doppler frequency shift - F_e = Transmitted frequency - v = Velocity of blood flow - θ = Angle between the ultrasound beam and direction of flow - c = Speed of sound in soft tissue (~1540

Professor
Dept. of Radio-Diagnosis
Hospital & Research Centre
Kolar-563 101

University Library
Resource Centre
SRIJAHER, Tamaka
KOLAR-563103

ABBREVIATIONS

Abbreviation	Full Term
FGR	Fetal Growth Restriction
MCA	Middle Cerebral Artery
NICU	Neonatal Intensive Care Unit
PSV	Peak Systolic Velocity
EDV	End-Diastolic Velocity
RI	Resistive Index
PI	Pulsatility Index
AGA	Appropriate Gestational Age
ROC	Receiver Operating Characteristic
AUC	Area Under the ROC Curve
TPE	Transient Periventricular Echodensities
GMH	Germinal Matrix Hemorrhage
IVH	Intraventricular Hemorrhage
PVL	Periventricular Leukomalacia
CBFV	Cerebral Blood Flow Velocity
HC	Head Circumference
AC	Abdominal Circumference
FL	Femur length
BPD	Biparietal diameter
SGA	Small for Gestational Age
CAN	Clinical Assessment of Nutritional Status
NEC	Necrotizing Enterocolitis
CBF	Cerebral Blood Flow
CPP	Cerebral perfusion pressure
CVR	Cerebrovascular resistance
MAP	Mean arterial pressure
ICP	Intracranial pressure
ACA	Anterior Cerebral Artery
CW	Continuous Wave
PW	Pulsed Wave
TCD	Transcranial Doppler
CPR	Cerebro-placental ratio
HIE	Hypoxic-Ischemic Encephalopathy
CUA	Cranial Ultrasound Abnormalities
REDF	Reversed End-Diastolic Flow
CNS	Central Nervous System
PPV	Positive Predictive Value
NPV	Negative Predictive Value
SDUAHER	Sri Devaraj Urs Academy of Higher Education and Research

ABSTRACT

Introduction

Fetal Growth Restriction (FGR) constitutes a significant obstetric complication with well-documented associations with neonatal morbidity, mortality, and long-term neurodevelopmental impairments. Alterations in cerebral hemodynamics, particularly within the middle cerebral artery (MCA), may reflect adaptive brain-sparing responses and serve as early indicators of neurological compromise. Despite advancements in perinatal imaging, the prognostic value of postnatal cerebral Doppler indices in FGR neonates remains inadequately explored.

Aim & Objectives:

To compare middle cerebral artery (MCA) Doppler characteristics between fetal growth-restricted (FGR) and gestational age-matched neonates. To evaluate the prognostic value of MCA Doppler parameters for early neurological outcomes and to assess the association between MCA Doppler findings and prolonged NICU stay in FGR neonates. To determine whether reversal of diastolic flow in MCA serves as a marker of mortality and neurological morbidity.

Methods:

A prospective, case-control observational study was conducted over an 18-month period at a tertiary academic center, enrolling 96 neonates (48 FGR and 48 AGA). Cranial ultrasonography with MCA Doppler evaluation was performed on postnatal days 1, 3, 7, and at 1 month using a standardized transtemporal approach. Doppler indices were analyzed and correlated with neurological outcomes and NICU duration. Statistical analyses included Mann-Whitney U, chi-square, Kruskal-Wallis tests, and receiver operating characteristic (ROC) curve analysis.

Results:

At 1 month, FGR neonates exhibited significantly elevated MCA PSV (43.10 cm/s vs. 39.90 cm/s; $p < 0.05$). Among all parameters, EDV demonstrated the highest predictive validity for unfavorable neurological outcomes, with area under the ROC curve (AUC) reaching 0.76 and odds ratios ranging from 1.20 to 1.30 ($p < 0.01$). While PI and RI exhibited high specificity, their sensitivity and AUC values were suboptimal. Lower PI and RI were significantly associated with extended NICU admissions and adverse neurological sequelae, such as periventricular leukomalacia and convulsions. Reversal of end-diastolic flow in MCA was observed exclusively in two FGR neonates who subsequently expired.

Conclusion:

Postnatal MCA Doppler assessment, particularly EDV, offers meaningful prognostic insight into early neurological outcomes in neonates with FGR. Routine serial evaluation of cerebral hemodynamics may facilitate timely risk stratification and clinical intervention. Further multicentric investigations with longitudinal follow-up are warranted to corroborate these findings and enhance their clinical applicability.

Keywords:

Fetal Growth Restriction (FGR), Middle Cerebral Artery (MCA), End-Diastolic Velocity (EDV), Resistive Index(RI), Pulsatility Index(PI).

TABLE OF CONTENTS

Sl. NO.	PARTICULARS	PAGE NO
1.	INTRODUCTION	1
2.	AIMS AND OBJECTIVES	5
3.	REVIEW OF LITERATURE	7
4.	MATERIALS AND METHODS	28
5.	RESULTS	33
6.	DISCUSSION	60
7.	SUMMARY	66
8.	LIMITATIONS	69
9.	CONCLUSION	71
10.	RECOMMENDATIONS	73
11.	BIBLIOGRAPHY	75
12.	ANNEXURE	80

LIST OF TABLES

Table No.	Table Title	Page No.
1	Doppler flow parameters	10
2	Features of symmetrical and asymmetrical FGR	13
3	Etiology of FGR	14
4	Diagnosis of FGR	15
5	Neonatal complications of FGR	16
6	Distribution of neonates according to their gender	34
7	Distribution of neonates according to their period of gestation	35
8	Distribution of neonates according to 5 minute APGAR score	37
9	Comparison of mean MCA Doppler parameters on day 1, 3, 7 and 1 month between AGA and FGR neonates after middle cerebral artery Doppler study	39
10	Comparison of neurological outcomes between AGA and FGR neonates	42
11	Comparison of mean PSV, EDV, PI and RI on day 1, 3, 7 and 1 month between FGR neonates with different neurological outcomes on middle cerebral artery Doppler.	44
12	Comparison of mean PSV, EDV, PI and RI on day 1, 3, 7 and 1 month between FGR neonates with different NICU stay duration.	48
13	ROC curves for PI at different time points with sensitivity and specificity for predicting unfavourable CNS outcomes	51
14	ROC curves for PSV at different time points with sensitivity and specificity for predicting unfavourable CNS outcomes	52
15	ROC curves for EDV at different time points with sensitivity and specificity for predicting unfavourable CNS outcomes	53
16	ROC curves for RI at different time points with sensitivity and specificity for predicting unfavourable CNS outcomes	54
17	Predictive ability of PSV, EDV, PI and RI for unfavourable CNS outcome	55

LIST OF FIGUERS

Figure No.	Figure Title/Description	Page No.
1	Doppler shift effect	9
2	Cerebral autoregulation sigmoid curve (x-axis: mean arterial blood pressure, y-axis: CBF).	18
3	Spectral Doppler waveform showing reversal of end-diastolic flow (REDF), indicative of reversed Resistance Index (RI) pattern.	22
4	The transtemporal approach to the middle cerebral artery in a neonate.	23
5	Trans-temporal approach color Doppler showing MCA.	24
6	Shows a pulsewave Doppler flow of middle cerebral artery (MCA), with peak systolic velocity (PSV), end-diastolic velocity (EDV), Pulsatility index (PI) and resistive index (RI).	25
7	Shows Ultrasound scanner Philips Epic 5 (a) and C8-5 MHz convex transducer (b).	31
8	Bar graph showing distribution of neonates according to their gender	35
9	Bar graph showing distribution of neonates according to their period of gestation	36
10	Bar diagram showing percentage distribution of neonates according to 5 minute APGAR score.	38
11	Bar diagram shows Comparison of mean PSV and EDV of MCA on day 1, 3, 7 and 1 month between AGA and FGR neonates.	40
12	Bar diagram shows comparison of mean PI and RI of MCA on day 1, 3, 7 and 1 month between AGA and FGR neonates.	41
13	Bar diagram showing comparison of neurological outcomes between AGA and FGR neonates.	43

14	Bar diagram showing Comparison of mean PSV and EDV of MCA on day 1, 3, 7 and 1 month between FGR neonates with different neurological outcomes.	46
15	Bar diagram showing Comparison of mean PI and RI of MCA on day 1, 3, 7 and 1 month between FGR neonates with different neurological outcomes.	47
16	Bar diagram showing comparison of mean PSV, EDV of MCA on day 1, 3, 7 and 1 month between FGR neonates with different NICU stay duration.	49
17	Bar diagram showing comparison of mean PI and RI of MCA on day 1, 3, 7 and 1 month between FGR neonates with different NICU stay duration.	50
18	Receiver operating characteristic curves of PI with sensitivity and specificity for predicting unfavourable CNS outcomes.	51
19	Receiver operating characteristic curves of PSV with sensitivity and specificity for predicting unfavourable CNS outcomes.	52
20	Receiver operating characteristic curves of EDV with sensitivity and specificity for predicting unfavourable CNS outcomes.	53
21	Receiver operating characteristic curves of RI with sensitivity and specificity for predicting unfavourable CNS outcomes.	54
22	Neurosonogram with MCA Doppler in PVL.	57
23	Neurosonogram with MCA Doppler of A preterm FGR male neonate at day 3, yellow arrow shows germinal matrix haemorrhage.	58
24	Neurosonogram with MCA Doppler of a Preterm AGA male neonate at day 3 shows no abnormal imaging / Doppler findings.	59

INTRODUCTION



INTRODUCTION

Fetal Growth Restriction (FGR) is a prevalent pregnancy complication characterized by a fetus not achieving its genetically predetermined growth potential, primarily due to pathological factors like placental dysfunction. This condition is the second most cause of perinatal morbidity and mortality which also predispose to poorer neurodevelopmental outcomes.^{1,2}

FGR infants are at risk for neonatal complications like asphyxia, hypothermia, hypoglycemia, and polycythemia, with potential long-term effects including growth retardation and neurodevelopmental disorders. Impaired oxygen and nutrient delivery to the fetal brain, compounded by oxidative stress and neuroinflammation, may predispose FGR neonates to neurologic outcomes such as cerebral palsy, cognitive and learning impairments, and structural deficits in gray and white matter.^{1,3}

Neurosonography is a vital, non-invasive imaging technique used to assess the neonatal brain, particularly in the early postnatal period. The portability, safety, and accessibility of neurosonography make it an ideal first-line tool in neonatal intensive care units for bedside evaluation of intracranial structures without the need for sedation or exposure to ionizing radiation.⁴

Its primary applications include the detection and monitoring of conditions such as transient periventricular echodensities (TPE), germinal matrix hemorrhage (GMH), intraventricular hemorrhage (IVH), periventricular leukomalacia (PVL), hydrocephalus, and other structural or ischemic brain injuries—conditions more frequently encountered in growth-restricted and preterm neonates.⁵

Recent advancements in high-frequency transducers, Doppler modalities, and standardized imaging protocols have significantly enhanced its diagnostic accuracy and anatomical detail in assessing cerebral structural and hemodynamic changes in neonates, especially those at risk of neurological compromise.^{4,5}

In the context of FGR fetuses, blood flow is redistributed to prioritize the brain, heart, and adrenal glands over the gut which persist in the early perinatal period of neonate. These alterations in cerebral blood flow reflect an adaptive response to hypoxia, commonly referred to as the "brain-sparing effect."⁶

FGR abnormalities, like TPE, PVL, and IVH are associated with cerebrovascular alterations in the early perinatal period which can be assessed in neurosonography. Therefore, identifying predictors of adverse outcomes in FGR is critical for the optimal management of high-risk pregnancies and affected neonates. Neurosonography along with postnatal Doppler ultrasound of the cerebral arteries, can provide valuable cerebrovascular parameters.^{7,8}

Doppler ultrasound of the MCA allows real-time assessment of cerebral hemodynamics by measuring parameters such as Resistive Index (RI), Pulsatility Index (PI), and Peak Systolic Velocity (PSV). Middle Cerebral Artery (MCA) Doppler accuracy may vary based on the operator technique and anatomical site of measurement and is less likely affected by the angle of insonation.⁵

A recent systematic review concluded that RI lacks sufficient evidence for routine monitoring in preterm infants. However, it may still hold diagnostic value in neonates with hypoxic-ischemic encephalopathy (HIE) and other early neurological manifestations.^{9,10}

Many studies have examined the relationship between altered pulsatility index and peak systolic velocity in fetal cerebral arteries and perinatal outcomes. However, there is a lack of research on postnatal cerebral blood flow characteristics and their impact on term neurodevelopment in FGR infants.¹¹

This study aims to compare the postnatal middle cerebral artery Doppler characteristics in neonates with fetal growth restriction to those of gestational age-matched controls.



AIMS & OBJECTIVES



AIMS & OBJECTIVES OF THE STUDY

1. To assess and compare the middle cerebral artery Doppler characteristics between fetal growth restricted neonates and gestational matched neonates.

Other Objectives

2. To evaluate the prognostic value of MCA Doppler parameters for early neurological outcomes in neonates and to assess the association between MCA Doppler findings and prolonged NICU stay in FGR neonates.
3. To determine whether reversal of diastolic flow in MCA serves as a marker of mortality and neurological morbidity.

REVIEW OF LITERATURE



REVIEW OF LITERATURE

3.1 DOPPLER ULTRASOUND

Sound Waves and Their Properties

“Ultrasound is a mechanical wave transmitted through a medium by molecular vibrations. These vibrations propagate in a sinusoidal pattern, causing compressions and rarefactions in the medium. The key characteristics of sound waves include:

Frequency (f): Measured in hertz (Hz), it denotes cycles per second.

Wavelength (λ): The distance between two points of maximum compression.

Propagation speed (c): The speed at which the wave moves through tissue, approximately 1540 m/s in soft tissue.

The relationship is defined by the equation: $c = \lambda \times f$

Diagnostic ultrasound typically uses frequencies between 2–30 MHz’s whereas, wavelengths used in transcranial ultrasonography is around the lower range of spectrum around 2 MH”.^{5,12}

Principles of Doppler Ultrasound

“The Doppler effect also known as the Doppler shift is first described by Christian Doppler in 1842, refers to the change in frequency of a wave caused by the relative motion between the source and the observer. Doppler shift is influenced by the moving source's velocity and direction relative to the reflector, resulting in a frequency change between the source and receiver as described in figure 1. A common example of this is the changing pitch of an ambulance siren as it

moves past an observer. In medical ultrasound, the Doppler effect is utilized to assess blood flow. As red blood cells move, they reflect ultrasound waves at different frequencies depending on their velocity and direction in relation to the transducer”.^{5,12}

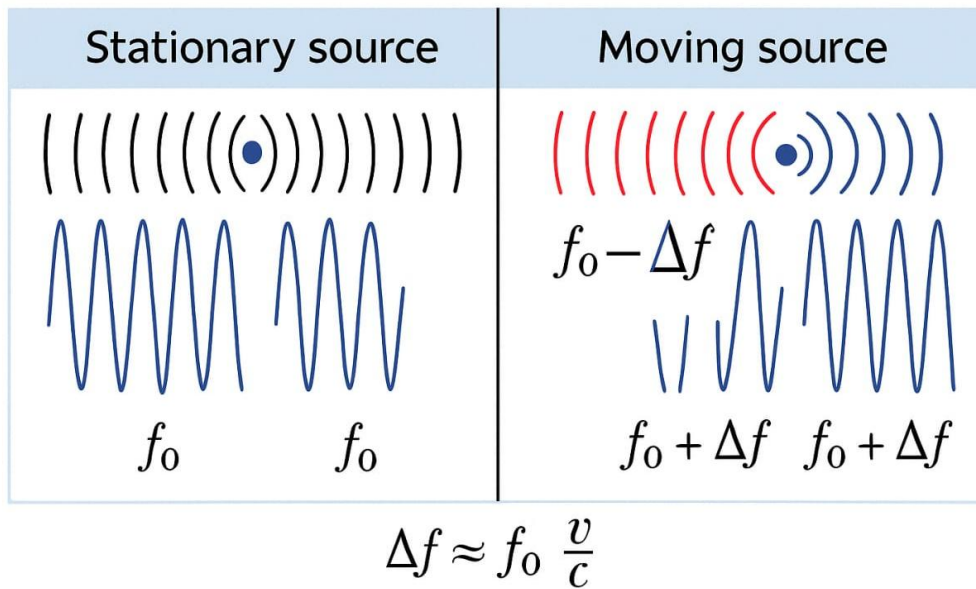


Figure 1. Doppler shift effect

“The Doppler frequency shift (F_d) is calculated using the Doppler equation:

$$F_d = (2 \times F_0 \times v \times \cos \theta) / c$$

Where:

- F_d = Doppler frequency shift
- F_0 = Transmitted frequency
- v = Velocity of blood flow
- θ = Angle between the ultrasound beam and direction of flow
- c = Speed of sound in soft tissue (~ 1540 m/s).¹²

Doppler Ultrasound Techniques:

Continuous Wave (CW) Doppler and Pulsed Wave (PW) Doppler are two ultrasound techniques used to measure blood flow velocities, each with distinct methods and applications.

CW Doppler uses two transducer elements: one for continuous transmission and the other for continuous reception. This method measures high-velocity flow without range specificity.

PW Doppler utilizes a single piezoelectric crystal that alternates between transmission and reception. It offers range resolution but is limited by the Nyquist limit, which can result in aliasing if surpassed.^{12,13}

Blood flow measurement

One of the following values are usually calculated to ascertain blood flow as show in table 1:

Doppler parameters	Explanation
Peak systolic velocity (PSV)	Highest peak velocity, Reflects systolic acceleration
End diastolic velocity (EDV)	Lowest peak velocity, Indicates downstream vascular resistance
Resistivity index (RI)	$PSV - EDV / PSV$
Pulsatility index (PI)	$PSV - EDV / MV$
Mean velocity (MV)	$PSV + EDV / 2$
Flow Direction	Normally antegrade. Reversed or absent flow suggests high intracranial pressure or critical perfusion

Table 1. Doppler flow parameters.¹³

Transcranial Doppler ultrasonography uses a low-frequency transducer on the scalp to visualize major cerebral arteries and measure cerebral blood flow velocity (CBFV). It helps assess changes in CBFV related to cerebrovascular diseases.⁵

The anterior fontanelle and transtemporal approach are most commonly used as the acoustic window for imaging. The MCA is usually visualized in the coronal or sagittal plane, adjacent to the sphenoid wing. Spectral Doppler is applied to measure blood flow velocities, with an angle of insonation less than 15° to maintain accuracy.^{14,15}

Postnatal Doppler ultrasound of the MCA is a vital non-invasive method for assessing cerebral perfusion in neonates adjunct to grayscale cranial ultrasonography, offering insight into the functional status of neonatal cerebral circulation. It is especially useful in neonates in early detection and monitoring of critical neurological conditions like HIE, sepsis, hydrocephalus, raised intracranial pressure, and hemodynamically significant patent ductus arteriosus (PDA). MCA Doppler complements grayscale neurosonography by providing insight into cerebral hemodynamics and autoregulation status.¹⁴

FGR

Epidemiology of FGR

FGR occurs significantly more often in developing and underdeveloped countries, with rates up to six times higher than in developed nations. This is particularly true in low- and middle-income countries, where many home births lack formal records, leading to underreporting and underdiagnosis of FGR.^{16,17}

In high-resource environments, FGR affects 3-9% of all pregnancies. In contrast, the incidence can reach nearly 30% in low-resource areas, underscoring the importance of socioeconomic and healthcare inequities.¹⁷

Seventy to eighty percent of FGR cases are late-onset, making it the most common type. Despite improvements in prenatal care, fewer than 30% of fetuses with a birth weight below the 10th percentile are identified before birth. Infants with undiagnosed FGR face a two to nine-fold increased risk of perinatal mortality and severe neurological issues, leading to poorer health outcomes.^{17,18}

What is FGR?

FGR occurs when a fetus fails to reach its genetically determined potential size, often leading to negative short- and long-term outcomes. It differs from small for gestational age (SGA), which is defined by a birth weight below the 10th percentile for gestational age based on population growth charts.^{1,11}

FGR can be classified by severity:

Moderate FGR refers to birth weight between the 3rd and 10th percentile, whereas **severe FGR** is Birth weight below the 3rd percentile.^{1,11}

Types of FGR:

Symmetrical FGR (hypoplastic small-for-date): Insult occurs early in gestation. All biometric parameters such as Head Circumference (HC), Abdominal Circumference (AC), Femur length (FL), Biparietal diameter (BPD) are proportionately reduced.

Asymmetrical FGR (malnourished babies): Insult occurs late in gestation. Only the abdominal circumference is reduced, while head size and femur length are preserved.

Mixed FGR: Often observed in developing countries, this condition exhibits characteristics of both symmetrical and asymmetrical FGR. It results from early fetal injury compounded by later placental insufficiency.^{3,19}

The characteristic features of Symmetrical and asymmetrical FGR are mentioned in table 2.

Characteristic	Symmetrical FGR	Asymmetrical FGR
Period of insult	Early gestation	Late gestation
Incidence	20 to 30%	70 to 80%
Etiology	Genetic/infectious	Utero-placental insufficiency
Antenatal scan	All parameters reduced	AC reduced, HC/FL/BPD preserved
Ponderal index	Normal (>2)	Low (<2)
Postnatal anthropometry	All reduced	Weight reduced only
HC–Chest circumference difference	< 3 cm	> 3 cm
Malnutrition features	Less likely	More likely
Prognosis	Poor	Better

Table 2. Features of symmetrical and asymmetrical FGR.³

Etiology of FGR

FGR represents a multifactorial condition resulting from pathological influences of maternal, placental, fetal, or genetic origin, either independently or through complex interactions among these factors. Various factors causing FGR are mentioned in table 3.^{3,20}

Factors causing FGR	
Maternal factors	<ul style="list-style-type: none"> ● Extremes of age (<16 or >35 years) ● Medical conditions: Hypertension, diabetes, renal disease, anemia, autoimmune diseases, antiphospholipid syndrome. ● Infections: Toxoplasma, Toxoplasmosis, Rubella, Cytomegalovirus, and Herpes, malaria, Tuberculosis, Urinary Tract Infections. ● Under nutrition and low socioeconomic status ● Substance use: Tobacco, alcohol, illicit drugs ● Medication exposure (e.g., anticonvulsants, anticoagulants, chemotherapy) ● Uterine anomalies or fibroids ● High physical workload ● Pre-pregnancy BMI <20 or >30 ● Previous SGA deliveries. ● Assisted reproductive technologies
Placental factors	<ul style="list-style-type: none"> ● Placental weight < 350 gram. ● Placental infarction, abruption, previa ● Abnormal vascular invasion or cord insertion ● Placental hemangiomas, circumvallate placenta ● Confined placental mosaicism (CPM) ● Infectious villitis, chronic villitis of unknown etiology (CVUE) ● Multiple gestation ● Partial molar pregnancy ● Preeclampsia and placental insufficiency
Fetal factors	<ul style="list-style-type: none"> ● Constitutional small fetuses (normal variant in 50–70%) ● Genetic & chromosomal abnormalities. ● Major congenital anomalies: Like Congenital heart disease, Congenital Diaphragmatic Hernia, neural tube defects. ● Intrauterine infections - Toxoplasma, Toxoplasmosis, Rubella, Cytomegalovirus, and Herpes, malaria, human immunodeficiency virus. ● Metabolic disorders: Galactosemia, neonatal diabetes, Inclusion-cell disease.

Table 3. Etiology of FGR.^{3,20}

Diagnosis of FGR

The assessment of high-risk mothers at risk for having an FGR fetus includes evaluating various methods/parameters and postnatal diagnosis of an FGR infant involves clinical examination, various anthropometric measurements as mentioned in table 4.^{21,22}

Diagnosis Stage	Methods/Parameters
Prenatal Diagnosis	Maternal history and risk factors Ultrasound with fetal biometry & dating of pregnancy. Doppler velocimetry (umbilical and cerebral arteries) Amniotic fluid assessment Cardiotocography for fetal monitoring
Postnatal Diagnosis	Birth weight <10th percentile for GA Clinical Assessment: Cephalization index, Ponderal Index, Clinical Assessment of Nutritional Status (CAN) Score, Mid- arm/head circumference ratio

Table 4. Diagnosis of FGR.^{21,22}

Complications of FGR:

FGR neonates are particularly vulnerable to a variety of postnatal complications due to their compromised intrauterine environment. These include perinatal asphyxia, meconium aspiration syndrome, hypothermia, hypoglycemia, polycythemia, neonatal jaundice, feeding difficulties and intolerance, necrotizing enterocolitis, intraventricular hemorrhage, periventricular leucomalacia and seizures. Furthermore, these infants are at heightened risk for neurodevelopmental and behavioral abnormalities, which may persist into later childhood as shown in table 5.²³

FGR Complications	Details
Perinatal Asphyxia	Increased risk due to chronic placental insufficiency and hypoxia.
Hypoglycemia	Common due to depleted glycogen stores and impaired gluconeogenesis.
Hypothermia	Frequent due to low fat stores and poor thermoregulation.
Polycythemia / Hyper-viscosity	Occurs from chronic intrauterine hypoxia-induced erythropoiesis.
Meconium Aspiration Syndrome	More frequent due to fetal distress and hypoxia
Necrotizing Enterocolitis (NEC)	Increased incidence, especially in preterm FGR neonates
Neonatal Sepsis	Higher susceptibility due to compromised immune function
Feeding Difficulties	Poor sucking, gut immaturity, often need for gavage feeds
Intraventricular Hemorrhage (IVH)	Increased in preterm FGR due to fragile germinal matrix and hypoperfusion
Periventricular Leukomalacia (PVL)	Strongly associated with chronic hypoxia and ischemia
Seizures	Seen due to HIE, hypoglycemia, or IVH
Delayed Neurodevelopment	Affects cognitive, language, motor domains in infancy and childhood
Cerebral Palsy	Elevated risk, especially in cases with PVL or extreme prematurity
Hearing and Vision Impairment	Due to perinatal hypoxia and brain injury
Behavioral & Learning Difficulties	Frequently seen in school age; includes attention, memory issues

Table 5. Neonatal complications of FGR.²³

PHYSIOLOGY OF NEONATAL CEREBRAL BLOOD FLOW (CBF)

CBF in neonates, particularly preterm infants, is subject to a range of physiological and pathological influences.

Physiology of CBF Autoregulation

Fluctuations in systemic arterial pressure in neonates directly impact CBF, increasing vulnerability to both hypo- and hyperperfusion which can cause perinatal brain injury. Altered hemodynamics in shock, sepsis, cerebral hemorrhage are associated with autoregulation and brain sparing.²⁴

Variable factors such as hematocrit, cardiac output, pCO₂, pO₂, blood glucose levels, and the total oxygen content of arterial blood influence cerebral blood flow. Fluctuations in cerebral dynamics occur at the level of friable arterioles and large arteries.²⁵

“CBF = Cerebral perfusion pressure (CPP) / Cerebrovascular resistance (CVR)

CPP = mean arterial pressure (MAP) – intracranial pressure (ICP).”²⁴

Cerebral autoregulation is typically represented as a sigmoid curve, with the plateau of autoregulation defined by its upper and lower limits. This autoregulatory mechanism operates effectively only when the MAP or CPP is within this plateau range.^{24,26}

“The cerebral autoregulation sigmoid curve in term (blue) and preterm newborns (red) is as follows: The autoregulatory plateau on the sigmoid curve indicates that cerebral perfusion pressure (CPP) is maintained by cerebral vaso-reactivity. Beyond the upper and lower limits of autoregulation, CBF becomes passive to blood pressure due to reduced vasoreactivity and the brain is at risk of hyperemic or hypoperfusion injury. With the gradual development of this autoregulation

from 26 to 33 weeks of gestation, the range of the autoregulation plateau is much narrower in preterm neonates (red dotted line) as depicted in figure 2”.²⁶

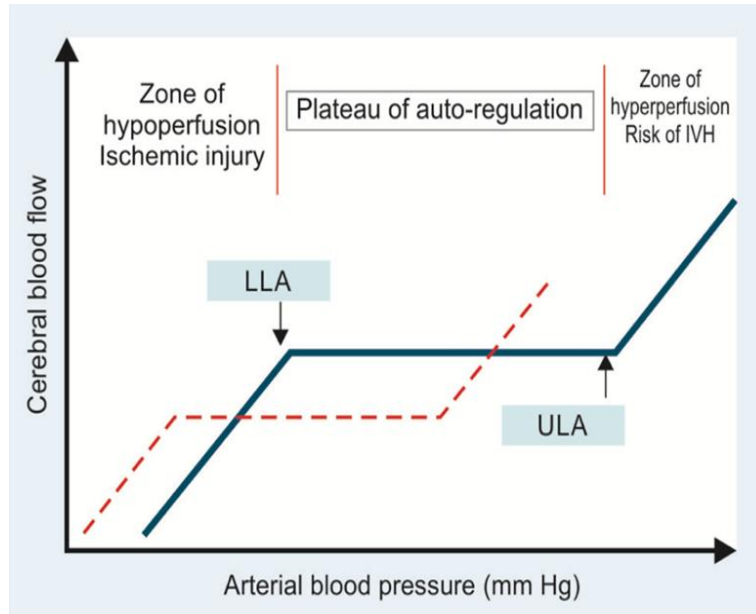


Figure 2. Cerebral autoregulation sigmoid curve

(x-axis: mean arterial blood pressure, y-axis: CBF).²⁶

Gestational and postnatal age

Numerous studies on the middle cerebral artery (MCA) and anterior cerebral artery (ACA) have shown that cerebral blood velocity increases with both advancing gestational age and each day following birth. However, a wide range of velocity values has been reported for each day after birth. The most significant change occurs within the first 12 hours of life, characterized by a decrease in the resistance index (RI).²⁷

Beat-to-Beat and Respiratory Variability

Neonatal velocity waveforms often show beat-to-beat and cyclical variation, influenced largely by respiration. This effect is more pronounced in preterm infants on mechanical ventilation, likely due to synchronization with ventilator cycles.²⁸

Arterial blood gas variations

Transient hyperoxia (increase in PO₂) can reduce cerebral blood flow velocity (CBFV) by about 3% for every 1 kPa increase in partial pressure of oxygen (PO₂). Conversely, carbon dioxide has a much stronger effect, increasing CBFV by approximately 30% per 1 kPa rise in partial pressure of carbon dioxide (PCO₂).^{29,30}

In full-term healthy neonates, hypercapnia raises diastolic velocity due to cerebral vasodilation. However, sick preterm infants show a muted CBFV response to rising carbon dioxide on their first day of life, which becomes more pronounced after 24 hours. This response appears to depend largely on changes in arterial pressure.²⁶

Blood viscosity and Hematocrit

Hemodilution in neonates resulted in low hematocrit value causing a significant increase in cardiac output and 20% increases in blood flow velocities of the internal carotid artery.^{26,31}

CEREBRAL BLOOD FLOW IN FGR

The adaptive hemodynamic alterations including cerebral blood flow redistribution, aimed at preserving brain perfusion under placental insufficiency is linked to FGR. This adaptation can be monitored using Doppler ultrasound during both antenatal and postnatal periods.³²

Antenatal Doppler Findings:

Doppler ultrasound plays a crucial role in detecting fetal growth restriction (FGR) and assessing fetal well-being. Typical findings include elevated umbilical artery RI/PI, with absent or reversed end-diastolic flow in severe cases. In the middle cerebral artery (MCA), decreased RI and PI reflect cerebral vasodilation and blood flow redistribution. A cerebroplacental ratio (CPR) <1.0

signifies brain-sparing and correlates with adverse outcomes. These changes often precede biophysical profile deterioration and assist in delivery planning, particularly in late-onset FGR.³³⁻³⁵

Perinatal (Postnatal) Doppler Evaluation:

- Postnatal transcranial Doppler (TCD) via the transtemporal window offers valuable insights into neonatal cerebral hemodynamics. In FGR neonates, the MCA often demonstrates elevated peak systolic velocity (PSV) and reduced resistance index (RI), reflecting persistent vasodilation due to impaired autoregulation. Similar patterns may be seen in the ACA and PCA, particularly in severely growth-restricted infants. Prolonged vasodilation and dysregulated cerebral blood flow postnatally can be linked to adverse neurodevelopmental outcomes.³⁶

CLINICAL APPLICATION OF DOPPLER

- Doppler imaging helps providing diagnostic approach to various conditions that may affect the flow velocity patterns and RI:¹⁴
- Systemic blood pressure variations and hypovolemic shock changes in the context of altered cerebrovascular autoregulation. Hypotension can significantly reduce flow, while hypertension may cause hyperemia and contribute to hemorrhage.
- Serial Doppler evaluations provide a better understanding of evolving cerebral hemodynamics.³⁷

Factors Affecting Neonatal Doppler Flow

Carbon Dioxide and Oxygen

- Hypercapnia leads to cerebral vasodilation and increased diastolic flow.
- Hypocapnia causes vasoconstriction and reduced diastolic flow.
- Hypoxia can transiently increase flow but may ultimately reduce it if autoregulation fails.^{24,26}

Hematocrit and Plasma Viscosity

- Elevated hematocrit increases viscosity thereby reducing flow velocities.
- Anemia may trigger compensatory increased flow, often detectable as increased PSV and EDV.^{26,38}

Doppler Flow in Pathological Conditions:

IVH is common in preterm infants due to fragile germinal matrix. Doppler findings show an elevated RI or PI with loss of beat-to-beat variability and low or absent diastolic flow. These findings suggest impaired autoregulation with increased risk for IVH.²⁶

PVL is an ischemic white matter injury in neonates. Doppler findings show an elevated RI in MCA, with decreased EDV. There are variable findings depending on the stage of disease.³⁹

Reversal of RI in neonates:

Under normal physiological conditions, the neonatal MCA exhibits a low-resistance waveform with forward end-diastolic flow, reflecting adequate cerebral perfusion, Absent or reversed diastolic flow causes reversal of RI wave pattern in the MCA Doppler as shown in figure 3. Studies have correlated these Doppler findings are associated with significant vascular resistance and poor prognosis, particularly in neonatal morbidity.⁴⁰

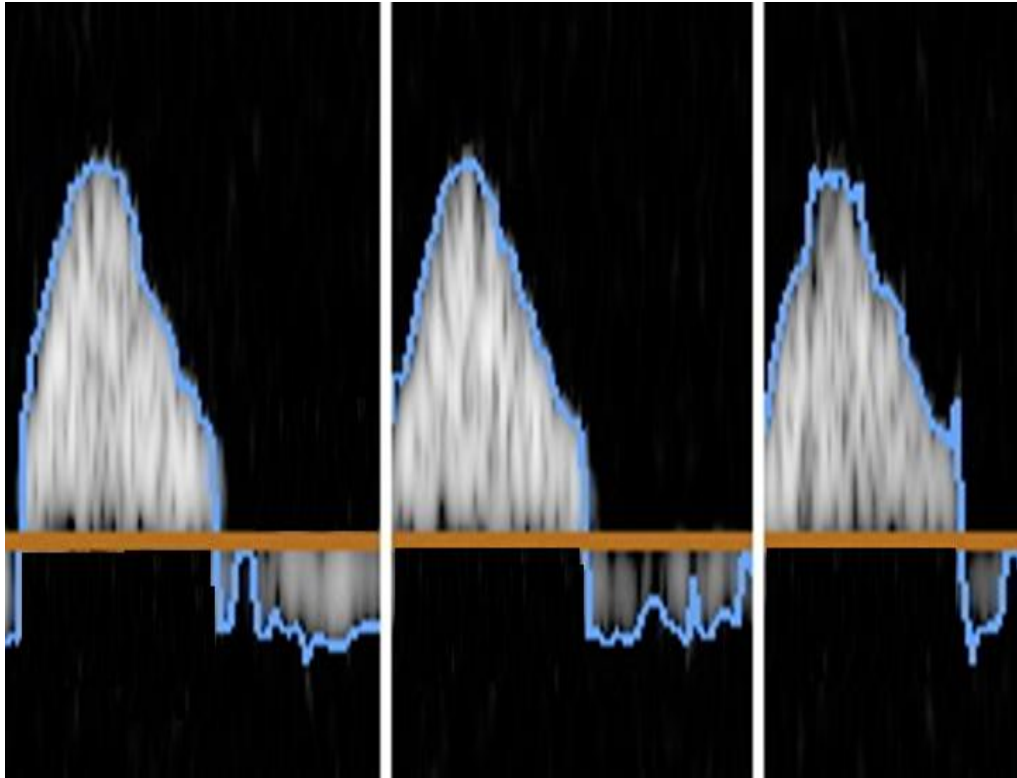


Figure 3: Spectral Doppler waveform showing reversal of end-diastolic flow (REDF), indicative of reversed Resistance Index (RI) pattern.

DOPPLER EXAMINATION

In neonatal cerebral doppler examination, the main approach for the middle cerebral arteries is transtemporal approach. Pulsed-wave Doppler with the angle of insonation ' θ ' close to zero will sample the vessel in the path of the ultrasound beam, to better estimate the flow velocities as shown in figure 4.⁵

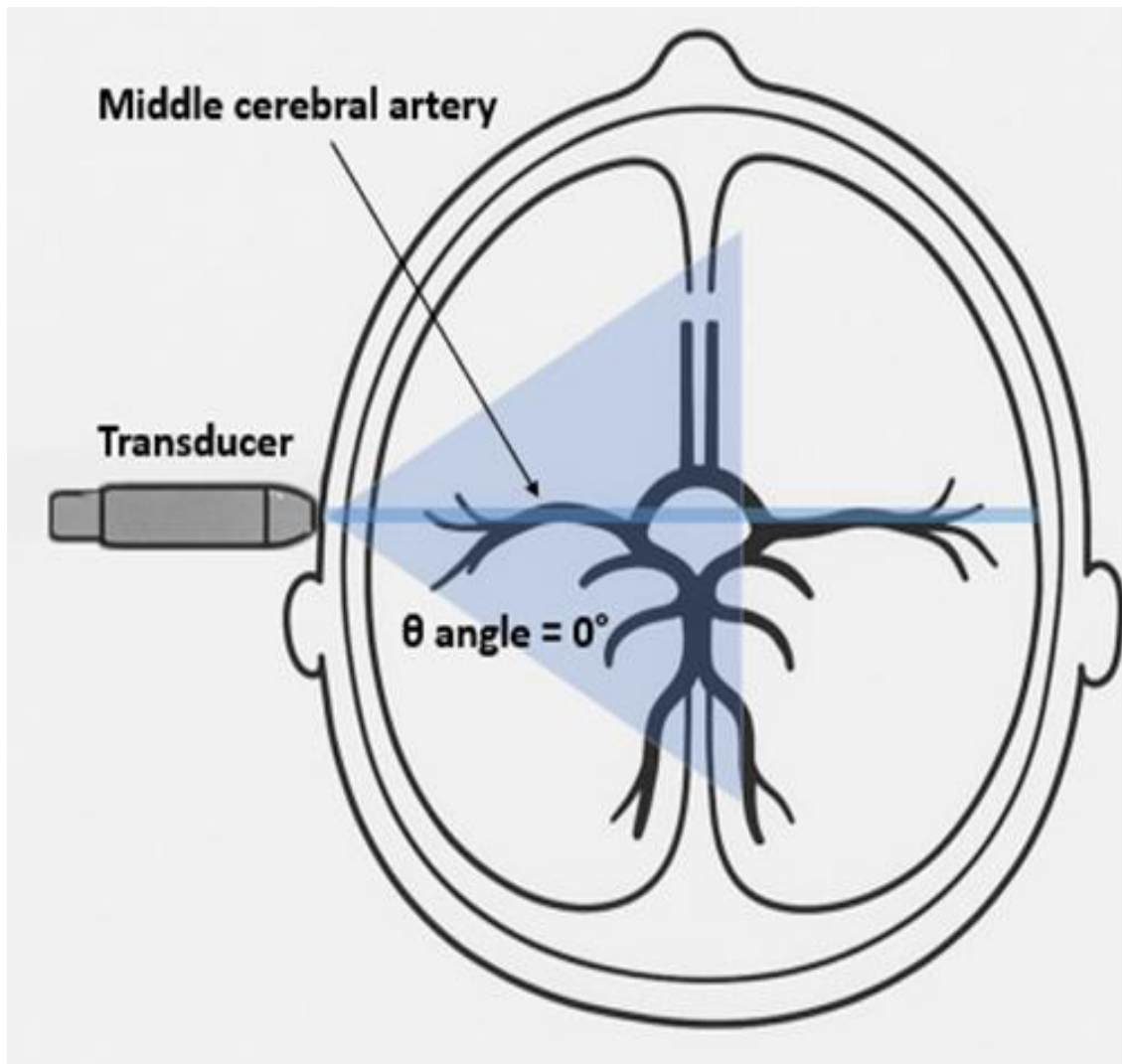


Figure 4. The transtemporal approach to the middle cerebral artery in a neonate.

Patient Positioning

The neonate is placed in **supine position**, with their **head and shoulders supported by a pillow** to ensure comfort for the baby, not crying or making manoeuvres that might alter flow, since these may be affected by movements. Optimal probe positioning is ensured.

TCD ultrasound is generally performed using two principal planes better visualization of vessels:

- **Axial Plane (Trans temporal)**
- **Coronal Plane (Anterior fontanelle)**

The **axial plane** is more commonly utilized and provides two imaging levels:

- **Mesencephalic view**
- **Diencephalic view**

The **mesencephalic plane** is the most clinically relevant for assessing cerebral arteries. It is obtained by placing the probe **parallel to the zygomatic arch**. The MCA is best assessed from the temporal window as shown in figure 5.⁵

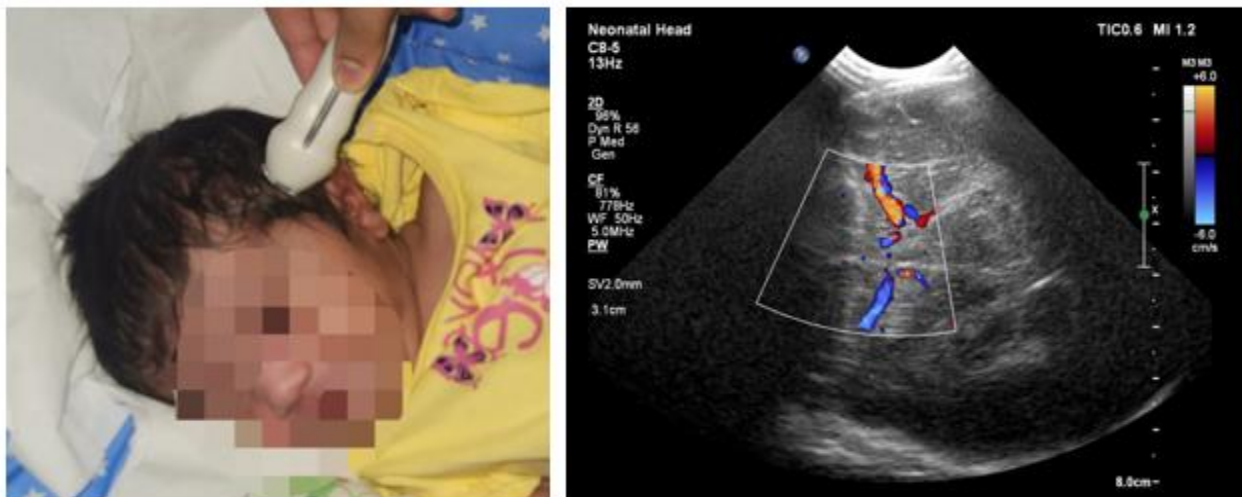


Figure 5. Trans-temporal approach color doppler showing MCA.

On transtemporal approach:

- The **hypoechoic "butterfly-shaped" midbrain** is typically seen in the center of the screen.
- Vessel of choice is identified by performing **color Doppler mode**. The **circle of Willis** was visualized, with the **MCA typically appearing red**, indicating flow toward the transducer.
- **Spectral Doppler** was then used to assess flow velocities along the MCA

Once the area of interest box is selected over a B mode, grayscale setting, the color doppler box is used to identify the MCA vessel with a forward flow, the flow sample pointer is then placed over the vascular lumen to get a doppler waveform as shown in figure 6. ⁵

For proper measurements, it is important to have good-quality spectra with fairly uniform signals.

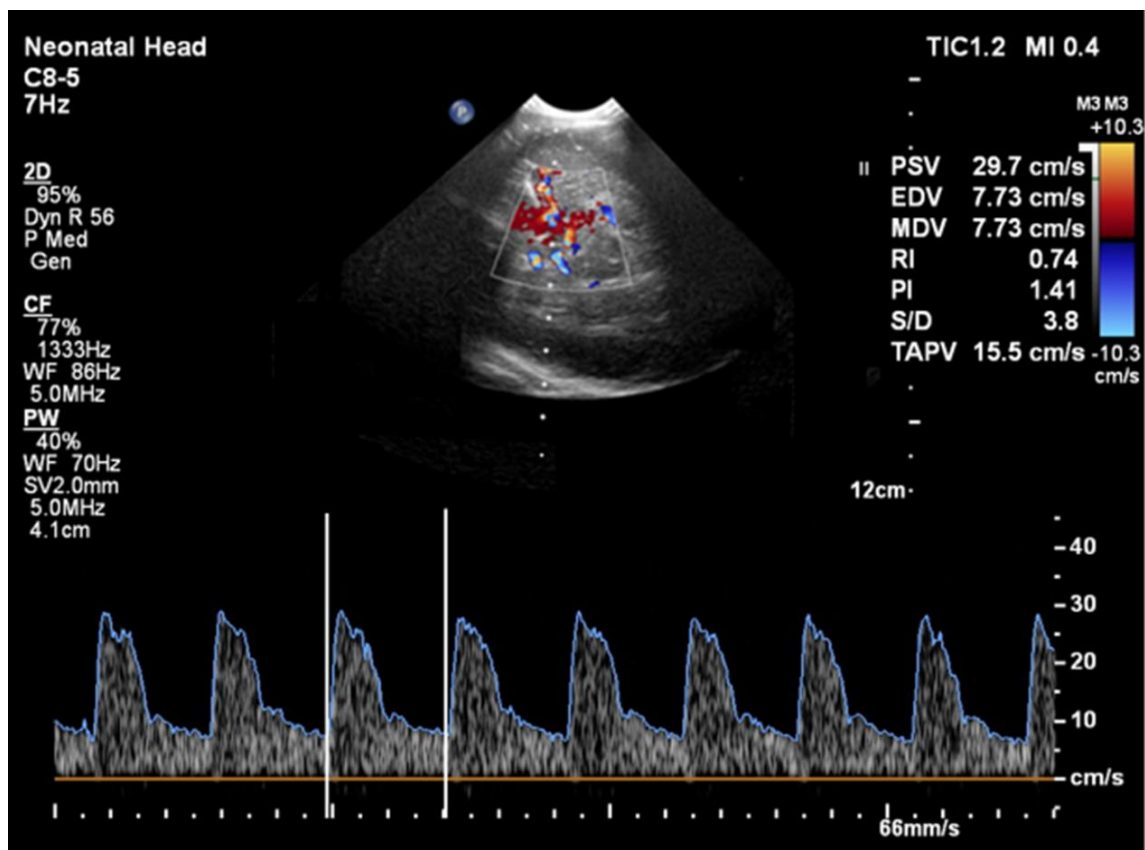


Figure 6. Shows a pulsewave Doppler flow of middle cerebral artery (MCA). with peak systolic velocity (PSV), end-diastolic velocity (EDV), Pulsatility index (PI) and resistive index (RI).

PREVIOUS SIMILAR STUDIES

Krishnamurthy et al. (2019) compared MCA Doppler characteristics in FGR and AGA neonates postnatally. While MCA PSV values are increased in both FGR and AGA groups from day 1 to day 3, EDV increased only in FGR infants, reflecting a compensatory brain-sparing response. Day 3 measurements showed significantly lower RI and PI in FGR infants, suggesting persistent altered cerebral autoregulation.³⁶

Venkatesh et al. (2020) investigated the prognostic value of diastolic flow reversal in the MCA in critically ill neonates. Presence of reversed diastolic flow was associated with significantly shorter survival (mean 1.3 h) compared to those without reversal (mean 133.8 days), underlining its potential as a strong mortality marker in neonatal intensive care settings.⁴⁰

Yakout et al. (2021) highlighted the value of umbilical artery, MCA, and ductus venosus Doppler in predicting neonatal outcomes. Significant associations were noted between adverse neonatal outcomes and abnormal MCA RI, PI, and DV A-wave indices in IUGR pregnancies, confirming their prognostic value.⁴¹

Jain et al. (2022) found that RI and PI values of ACA and MCA are significantly low, while PSV and EDV values are significantly high in HIE cases compared to controls. A strong association was found between Doppler indices and the clinical severity of HIE, suggesting that these parameters can be effective in early stratification and monitoring.⁴²

Kumar et al. (2024), have underscored the clinical relevance of Doppler-derived parameters such as the resistivity index (RI) in the anterior cerebral artery (ACA) and middle cerebral artery (MCA) for detecting hypoxic brain injury. Our findings align with this growing body of evidence, demonstrating that high RI values in ACA and MCA are indicative of impaired cerebral autoregulation. Moreover, Kumar et al. found that high resistance index (RI) and low mean cerebral blood flow velocities (CBFV) in the anterior cerebral artery (ACA) during the early neonatal period were significantly linked to negative neurodevelopmental outcomes.²⁶

MATERIALS & METHODS



MATERIALS AND METHODS

STUDY DESIGN: A case-control observational study.

STUDY DURATION: 18 month duration (May 2023 to November 2024).

STUDY SITE: Department of Radio Diagnosis and Paediatrics at R.L. Jalappa Hospital and Research Center attached to Sri Devaraj Urs Medical College, SDUAHER, Kolar

STUDY POPULATION: All neonates, delivered at R.L. Jalappa Hospital and Research center, Sri Devaraj Urs Academy of Higher Education and Research, Kolar.

INCLUSION CRITERIA

Cases - Fetal growth restriction (FGR) neonates

Neonates with any abnormal IUGR Doppler profiles and birth weight of < 10th percentile.

Controls - Appropriate gestation age (AGA) neonates

Neonates with normal antenatal scans and birth weight ranging between 10 percentiles to 90 percentile.

EXCLUSION CRITERIA

1. Congenital deformities.
2. 5 min Apgar score < 7,
3. Postnatal resuscitation.
4. Genetic conditions.
5. Cardiovascular disorders.
6. Sepsis.
7. Metabolic disorders.

SAMPLE SIZE AND SAMPLING TECHNIQUE

The sample size was calculated by utilizing the difference in Mean RI on day 3 between AGA and FGR group as 0.79 ± 0.07 and 0.72 ± 0.10 , from the study Mohan B Krishnamurthy et. al.²⁶

Using these values at 95% Confidence limit and 80% power sample size of 43 was obtained in each group by using the below mentioned formula and Med calc sample size software. With 10% nonresponse sample size of $43 + 4.3 \approx 48$ cases are included in each group.

“Sample Size Estimation Formula: $N = 2 SD^2 (Z_{\alpha/2} + Z_{\beta})^2 / d^2$ ”

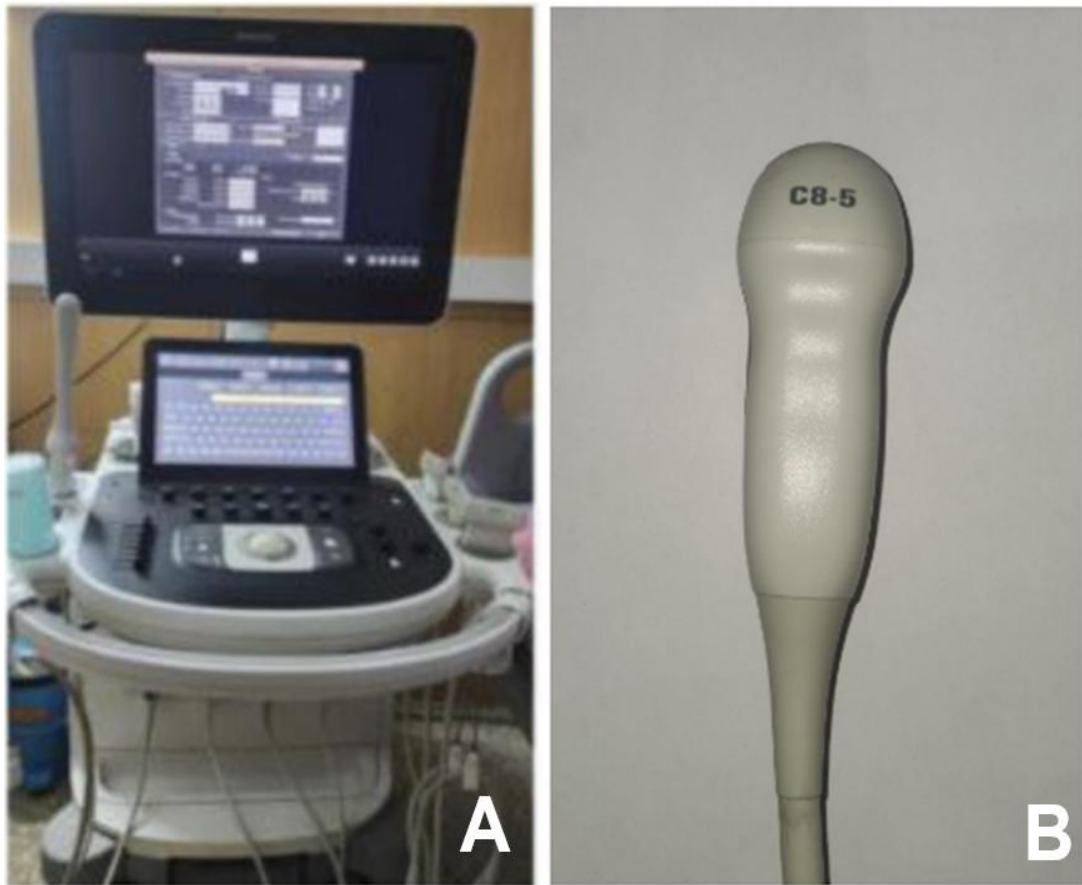
- Where $Z_{\alpha/2}$ is the critical value of the Normal distribution at $\alpha/2$ (e.g. for a confidence level of 95%, α is 0.05 and the critical value is 1.96).
- Z_{β} is the critical value of the Normal distribution at β (e.g. for a power of 80%, β is 0.2 and the critical value is 0.84).
- **SD** is the standard deviation from previous study population variance.
- **d** is the largest difference between two mean.”⁴³

During the study duration, consecutive 48 IUGR neonates and 48 AGA neonates fulfilling the inclusion criteria were included.

DATA COLLECTION

Data were collected using a semi-structured study proforma. When a neonate was referred to the Department of Radio-diagnosis or Pediatrics and met the study's inclusion criteria, a detailed history was taken from the parent or guardian.

Cranial ultrasonography and middle cerebral artery (MCA) Doppler assessments were obtained on day 1, day 3, and day 7 with the neonate in the supine position. The MCA Doppler was performed using the Philips EPIQ5 machine with an 8-5 MHz curvilinear transducer as shown in Figure 7.



Figures 7: Shows Ultrasound scanner Philips Epic 5 (A) and C8-5 MHz convex Transducer (B).

Brain structures were visualized through the fontanelles as acoustic windows as well as transtemporal in the coronal and sagittal planes. Doppler evaluation of both side MCA was done simultaneously in neonates to obtain a spectral tracing and RI, PI, PSV and EDV. Mean value of the readings taken for documentation. Follow up cranial ultrasonography with MCA doppler done in neonates at 1 month of age.

The following precautions were followed when doing Middle cerebral artery Doppler:

Angle of insonation was kept within 15 deg while taking doppler parameters.

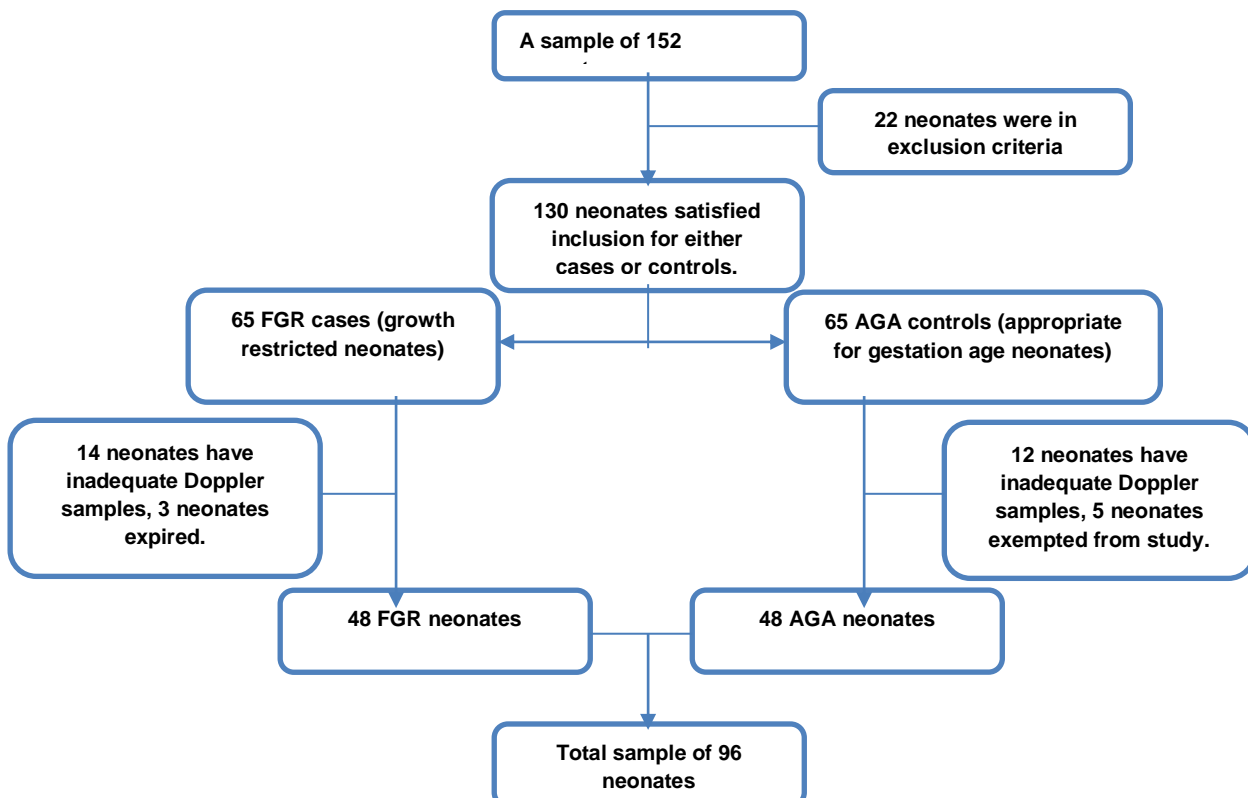
STATISTICAL ANALYSIS

The analysis profiled patients using demographic, laboratory, and clinical parameters. Quantitative data were presented as means and standard deviations, while ordinal data were shown as counts and percentages. Cross tables were created, and associations were tested with the chi-square test. The Student t-test compared quantitative parameters, with a p-value of less than 0.05 considered statistically significant. All analyses were performed using SPSS software, version 24.0.

ETHICAL STATEMENT

The study protocol adheres to the Declaration of Helsinki and received approval from the Institutional Ethics Committee prior to starting the research. All the parents / guardians of the neonates provided written informed consent. It was clarified to the parents / guardians that no harm was intended, and they were fully informed before giving their consent. Additionally, parents / guardians did not incur any extra costs due to their involvement in the study.

Sample data collection with justification:



RESULTS



RESULTS

Distribution of neonates according to their gender

Gender		Study group		Study group
		AGA	AGA	
Female	N	21	21	42
	%	44%	44%	44%
Male	N	27	27	54
	%	56%	56%	56%
Total	N	48	48	96
	%	100%	100%	100%
		p value* = 0.99		

*analyzed using chi-square test

Table 6. Distribution of neonates according to their gender

Each group (AGA and SGA) contained 48 neonates, totaling 96 participants. Among these, 44% were female (21 in each group), and 56% were male (27 in each group), indicating a balanced distribution across the groups as depicted in table 6 and figure 8. The chi-square test yielded a p-value of 0.99, suggesting no statistically significant difference in gender distribution between the AGA and FGR groups.

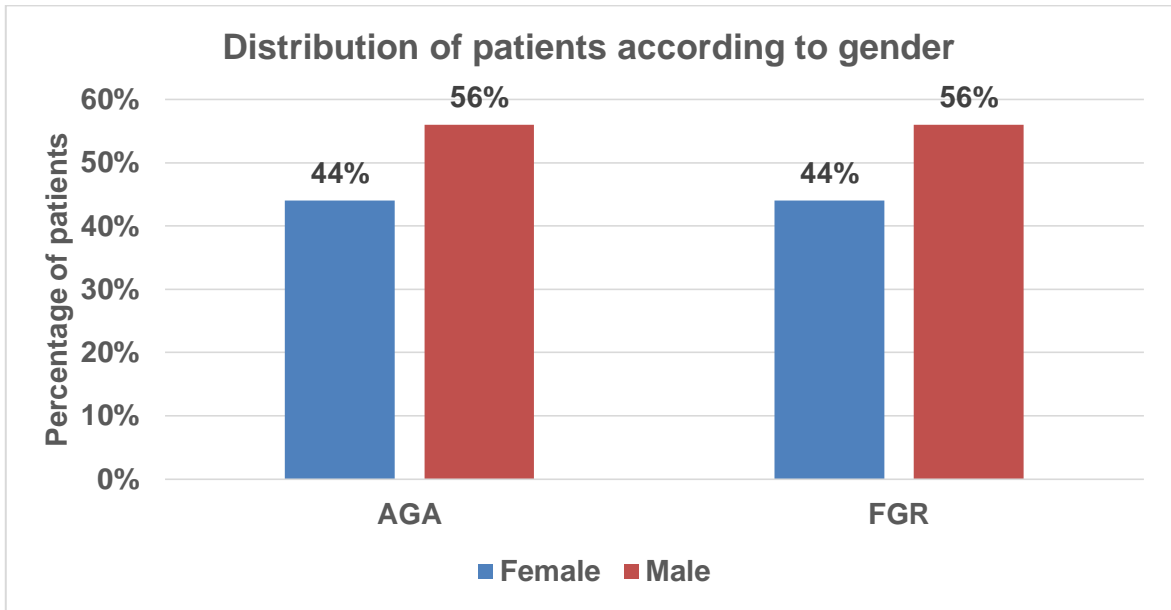


Figure 8. Bar graph showing distribution of neonates according to their gender

Distribution of neonates according to their period of gestation

Period of Gestation		Study group		Study group
		AGA	AGA	
Preterm (<37 weeks)	N	28	28	56
	%	58%	58%	58%
Term (37 to 41 weeks)	N	20	20	40
	%	42%	42%	42%
Total	N	48	48	96
	%	100%	100%	100%
		p value* = 0.99		

*analyzed using chi-square test

Table 7. Distribution of neonates according to their period of gestation

In both groups, 58% of neonates were born preterm (less than 37 weeks), and 42% were born at term (between 37 to 41 weeks). The total preterm births were 56 and term births were 40 as depicted in table 7 and figure 9. Similar to gender distribution, the p-value was 0.99, indicating no statistically significant difference in gestational age between AGA and FGR neonates.

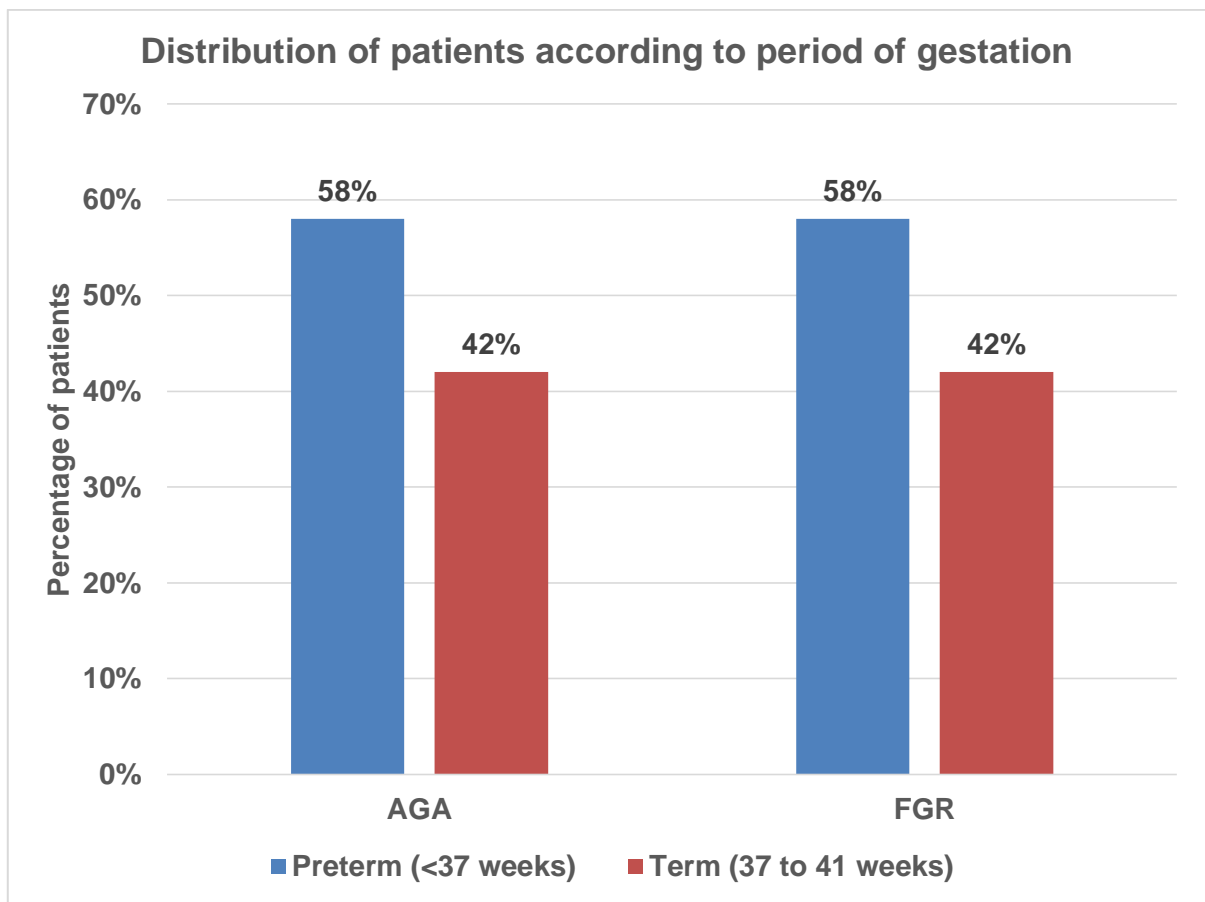


Figure 9. Bar graph showing distribution of neonates according to their period of gestation

Distribution of neonates according to 5 minute APGAR score

5 MIN APGAR SCORE		Study group		Total
		AGA	FGR	
7	N	8	19	27
	%	17%	40%	28%
8	N	13	13	26
	%	27%	27%	27%
9	N	12	11	23
	%	25%	23%	24%
10	N	15	5	20
	%	31%	10%	21%
Total	N	48	48	96
	%	100%	100%	100%
		p value* < 0.01		
*analyzed using chi-square test				

Table 8. Distribution of neonates according to 5 minute APGAR score

Although neonates with APGAR scores below 7 were excluded from the study, the AGA group demonstrated a more favorable distribution of scores, with 31% scoring 10, while only 10% of FGR neonates achieved this. A substantial 40% of FGR neonates had a score of 7 compared to just 17% in AGA. Scores of 8 and 9 were relatively evenly distributed as depicted in table 8 and figure 10. The chi-square test revealed a p-value of less than 0.01, indicating a statistically significant difference, with FGR neonates showing lower APGAR scores overall.

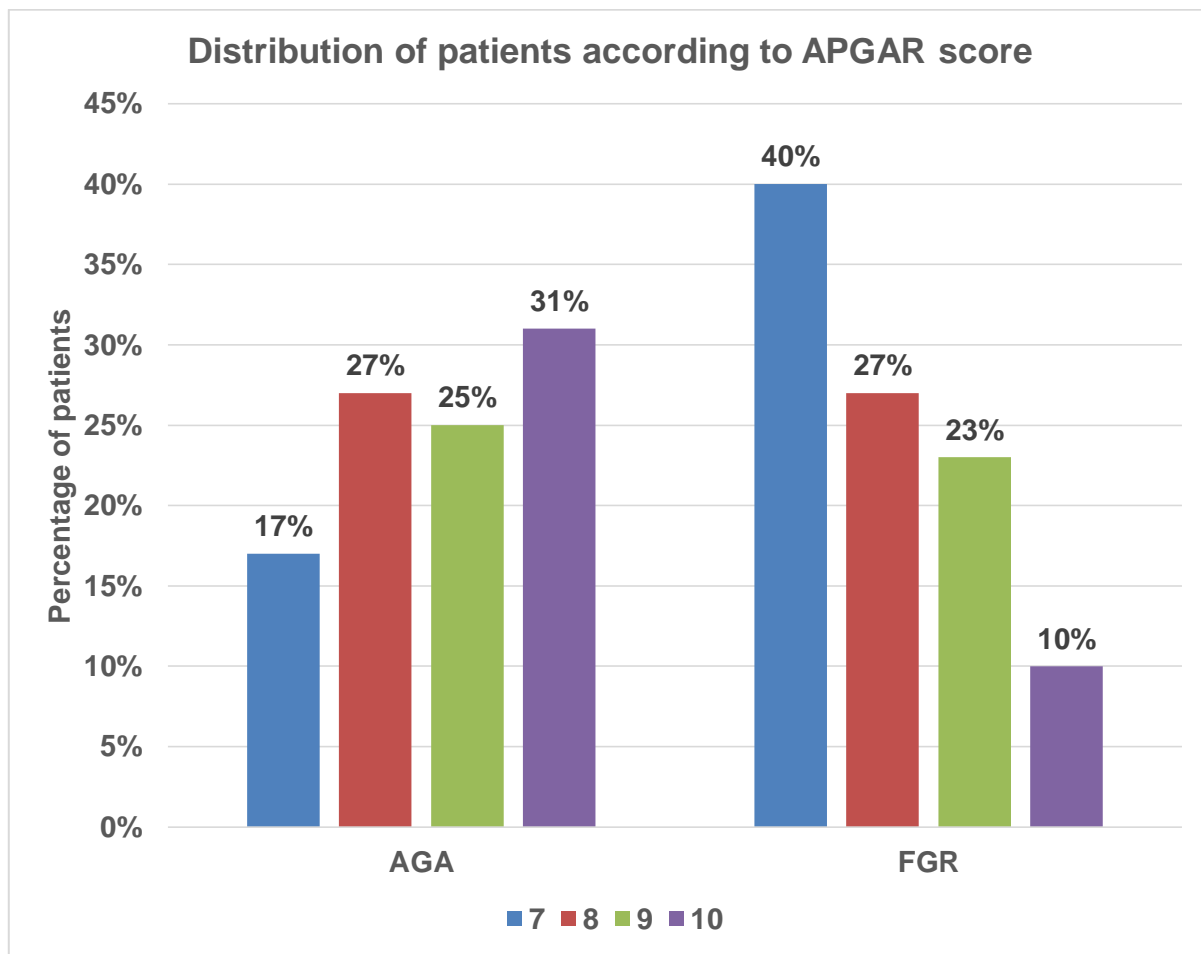


Figure 10. Bar diagram showing percentage distribution of neonates according to 5 minute APGAR score.

Comparison of mean MCA Doppler parameters on day 1, 3, 7 and 1 month between AGA and FGR neonates after middle cerebral artery doppler study.

Time points	Doppler Parameters	AGA		FGR		p value*
		Median	SD	Mean	SD	
Day 1	PSV	33.40	5.40	32.40	5.40	0.41
	EDV	10.60	2.90	10.90	3.90	0.98
	PI	1.10	0.10	1.19	0.20	0.71
	RI	0.68	0.06	0.69	0.10	0.64
Day 3	PSV	34.40	5.60	33.40	4.60	0.41
	EDV	10.70	3.10	10.8	3.8	0.69
	PI	1.18	0.15	1.17	0.21	0.94
	RI	0.69	0.06	0.68	0.09	0.88
Day 7	PSV	37.10	5.90	35.10	5.70	0.12
	EDV	11.30	3.10	11.20	4.40	0.31
	PI	1.20	0.15	1.19	0.20	0.96
	RI	0.70	0.06	0.69	0.09	0.97
1 month	PSV	39.90	6.30	43.10	6.90	< 0.05
	EDV	11.80	3.60	13.10	4.10	0.14
	PI	1.22	0.19	1.21	0.19	0.98
	RI	0.70	0.08	0.70	0.08	0.85
*analyzed using Mann Whitney test						

Table 9. Comparison of mean MCA Doppler parameters on day 1, 3, 7 and 1 month between AGA and FGR neonates after middle cerebral artery doppler study

This describes the longitudinal comparison of cerebral blood flow parameters from middle cerebral artery Doppler studies (including PSV, EDV, PI, and RI) between AGA and FGR neonates on days 1, 3, 7, and at 1 month. Most values across time points did not show statistically significant differences, except at 1 month, where FGR neonates had significantly higher PSV (mean 43.10) compared to AGA neonates (mean 39.90), with a p-value of <0.05. Other parameters such as EDV, PI, and RI showed no significant differences at any time point as depicted in table 9, figures 11 and 12.

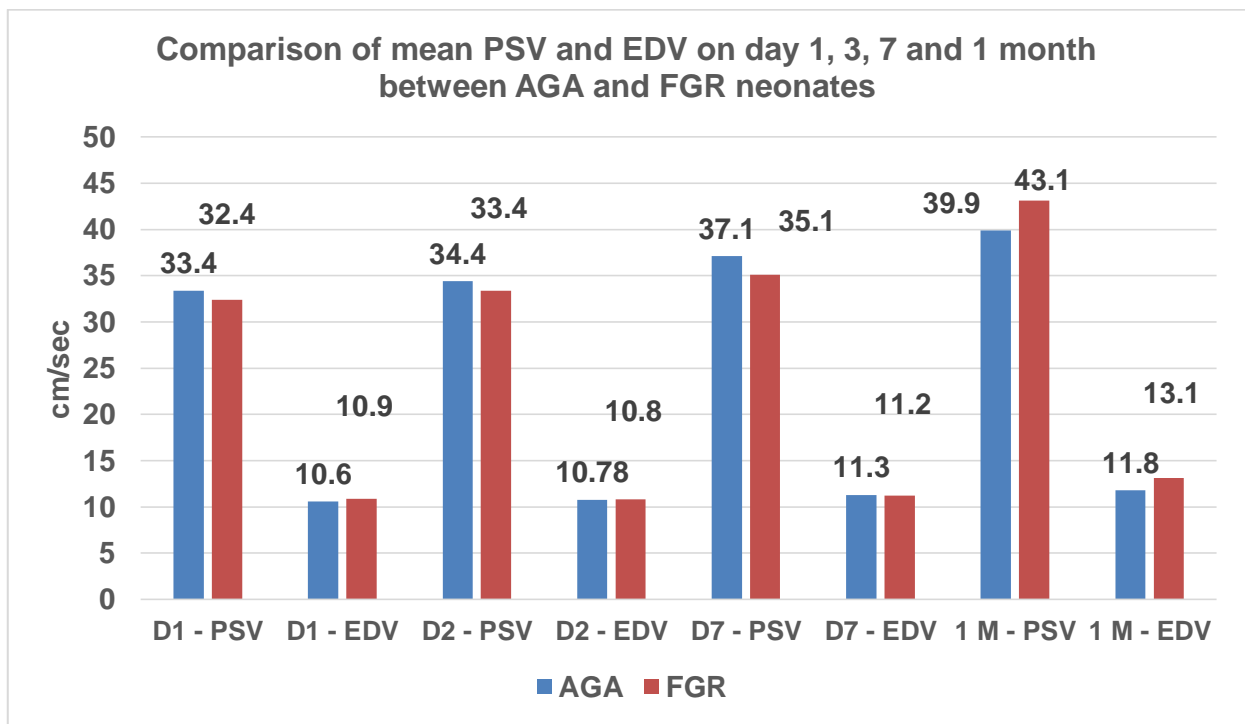


Figure 11. Bar diagram shows Comparison of mean PSV and EDV of MCA on day 1, 3, 7 and 1 month between AGA and FGR neonates.

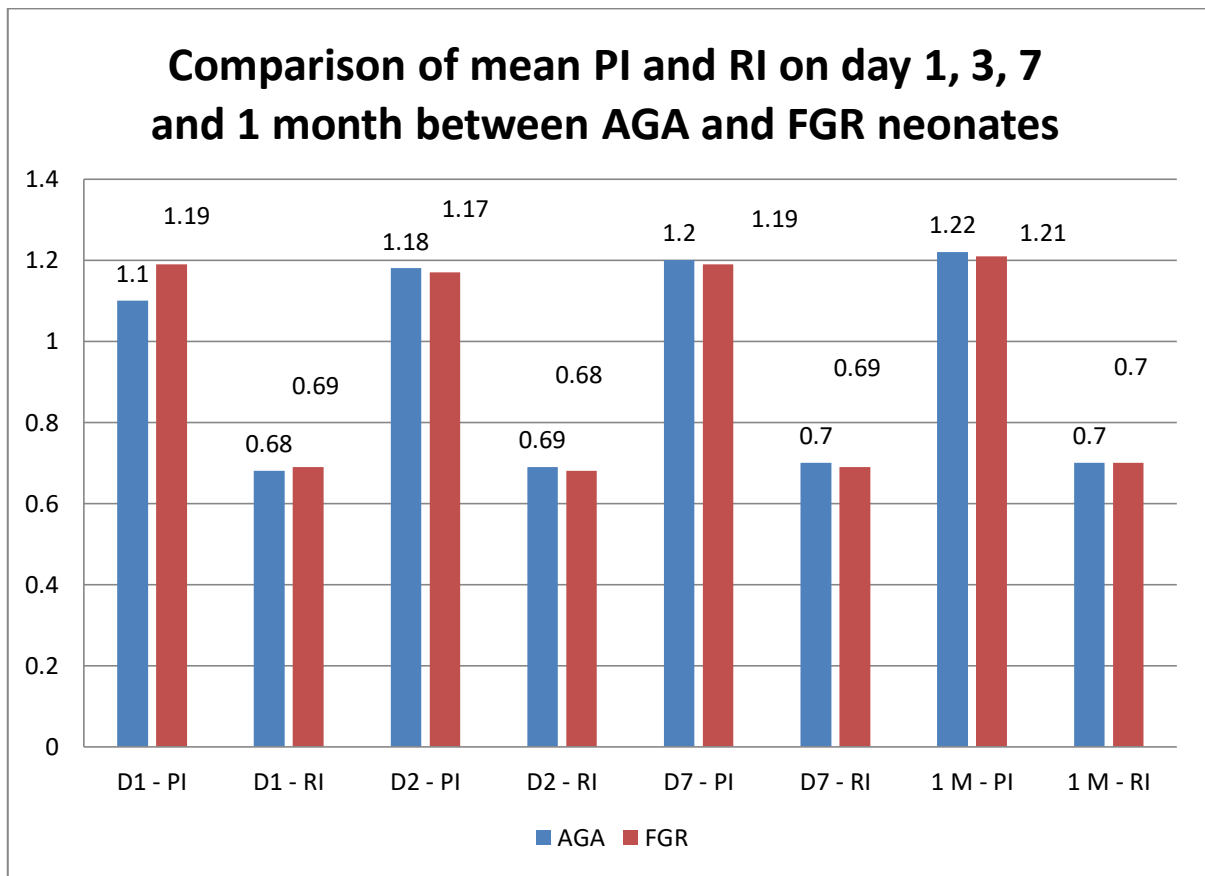


Figure 12. Bar diagram shows comparison of mean PI and RI of MCA on day 1, 3, 7 and 1 month between AGA and FGR neonates.

Comparison of neurological outcomes between AGA and FGR neonates.

Neurological outcome		Study group		Study group
		AGA	AGA	
Convulsions	N	2	9	11
	%	4%	19%	11%
Germinal matrix hemorrhage	N	0	2	2
	%	0%	4%	2%
PVL	N	0	2	2
	%	0%	4%	2%
Uneventful	N	46	35	81
	%	96%	73%	84%
Total	N	48	48	96
	%	100%	100%	100%
		p value* < 0.05		

*analyzed using chi-square test,

N-number of neonates, %-percentage

Table 10. Comparison of neurological outcomes between AGA and FGR neonates.

Convulsions were observed in 19% of FGR neonates compared to only 4% of AGA neonates. Germinal matrix hemorrhage and periventricular leukomalacia (PVL) were exclusively found in FGR infants (each in 4%) as depicted in table 10 and figure 13. A significantly higher proportion of AGA neonates (96%) had uneventful neurological outcomes compared to 73% in the FGR group. This difference was statistically significant with a p-value of <0.05.

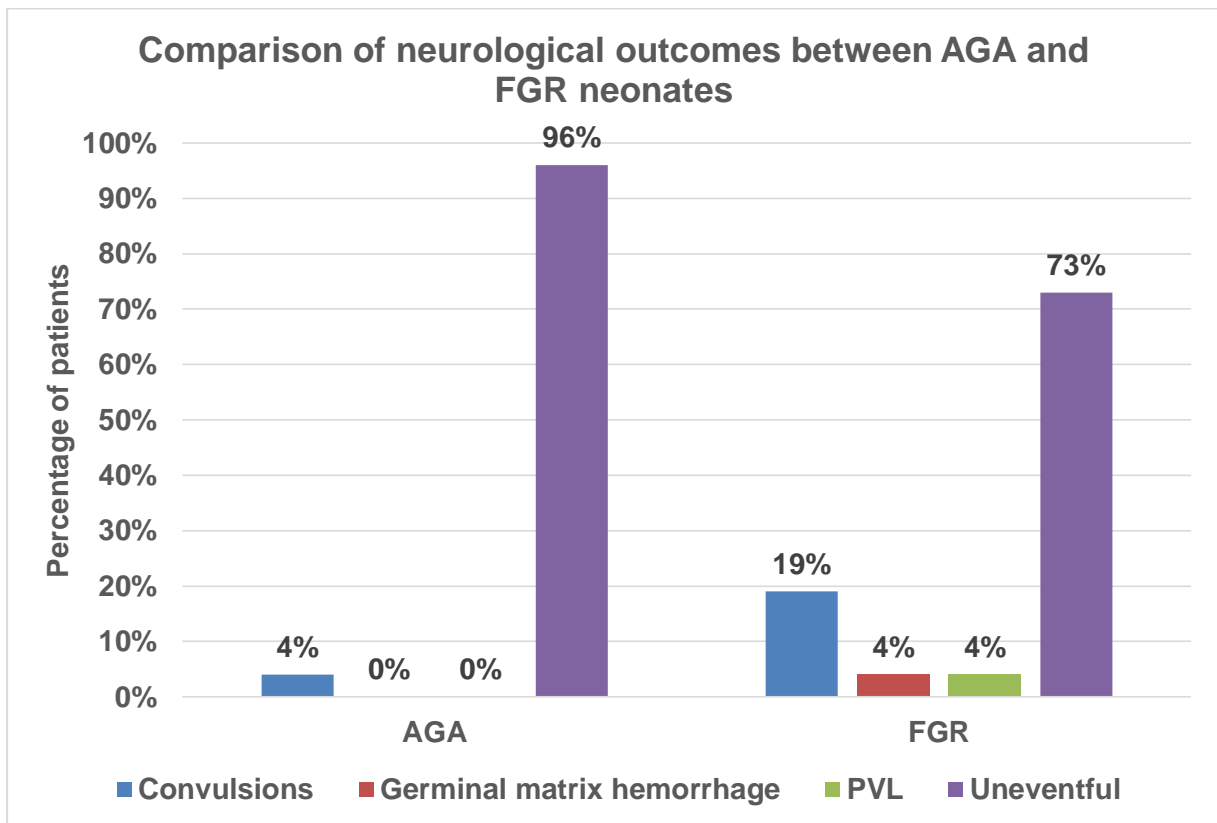


Figure 13. Bar diagram showing comparison of neurological outcomes between AGA and FGR neonates.

Comparison of mean MCA doppler parameters on day 1, 3, 7 and 1 month between FGR neonates with different neurological outcomes.

Time points	Doppler parameter	Neurological outcome								p value*
		Convulsions		Germinal matrix hemorrhage		PVL		Uneventful		
		Median	SD	Median	SD	Median	SD	Median	SD	
Day 1	PSV	33.90	4.40	35.65	3.61	29.70	3.30	32.00	4.90	0.51
	EDV	14.30	3.80	19.40	1.60	5.80	0.40	9.90	2.70	< 0.01
	PI	0.96	0.21	0.72	0.01	1.48	0.02	1.19	0.15	< 0.01
	RI	0.58	0.10	0.46	0.01	0.81	0.01	0.69	0.06	< 0.01
Day 3	PSV	34.50	4.80	36.65	4.20	32.60	4.80	33.00	4.67	0.77
	EDV	14.20	3.78	18.30	2.90	5.70	0.50	9.81	2.77	< 0.01
	PI	0.97	0.20	0.79	0.04	1.54	0.02	1.22	0.14	< 0.01
	RI	0.59	0.09	0.49	0.02	0.82	0.01	0.70	0.06	< 0.01
Day 7	PSV	36.50	5.90	41.30	9.60	35.40	5.90	34.40	5.51	0.76
	EDV	14.59	4.33	20.95	5.16	6.35	1.01	10.04	3.19	< 0.05
	PI	1.00	0.18	0.79	0.01	1.52	0.01	1.24	0.14	0.98
	RI	0.61	0.09	0.49	0.01	0.82	0.01	0.71	0.06	0.98
1 month	PSV	47.10	5.80	43.70	2.70	36.20	8.27	42.30	6.92	0.41
	EDV	17.30	2.94	20.85	2.90	6.65	0.78	11.84	2.91	< 0.01
	PI	1.04	0.20	0.84	0.07	1.50	0.06	1.26	0.13	< 0.05
	RI	0.62	0.09	0.53	0.04	0.81	0.02	0.72	0.05	< 0.01

*analyzed using Kruskal Wallis test

Table 11. Comparison of mean PSV, EDV, PI and RI on day 1, 3, 7 and 1 month between FGR neonates with different neurological outcomes on middle cerebral artery doppler (n=48)

On day 1, EDV, PI, and RI were significantly different across groups, with particularly low EDV and high PI and RI seen in neonates with PVL. Similar trends were observed on subsequent days as depicted in table 11 and figures 14 and 15. By 1 month, neonates with PVL continued to show the lowest EDV and highest PI/RI, again with statistically significant differences ($p < 0.05$ or < 0.01 depending on the parameter).

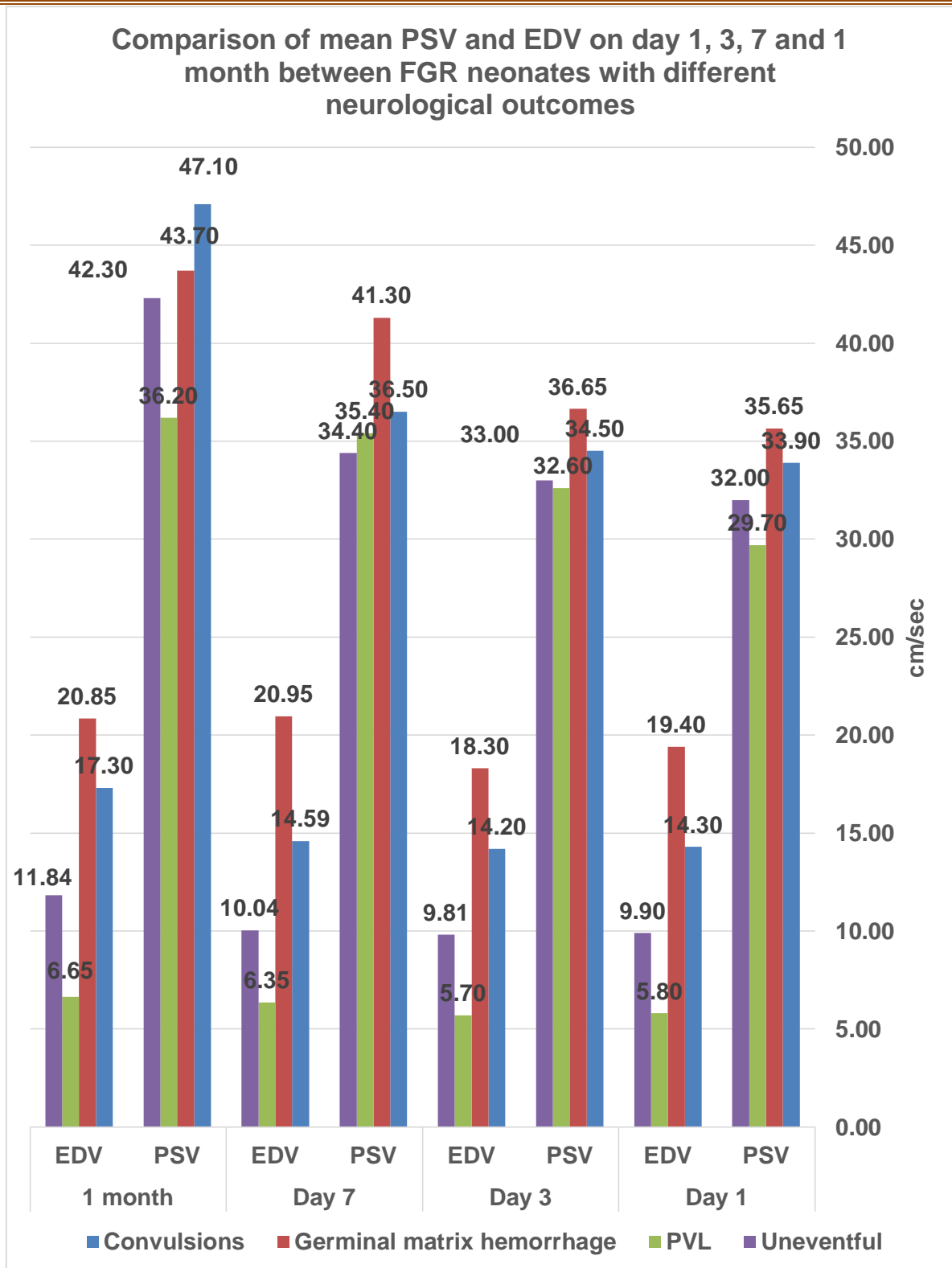


Figure 14. Bar diagram showing Comparison of mean PSV and EDV of MCA on day 1, 3, 7 and 1 month between FGR neonates with different neurological outcomes (n=48).

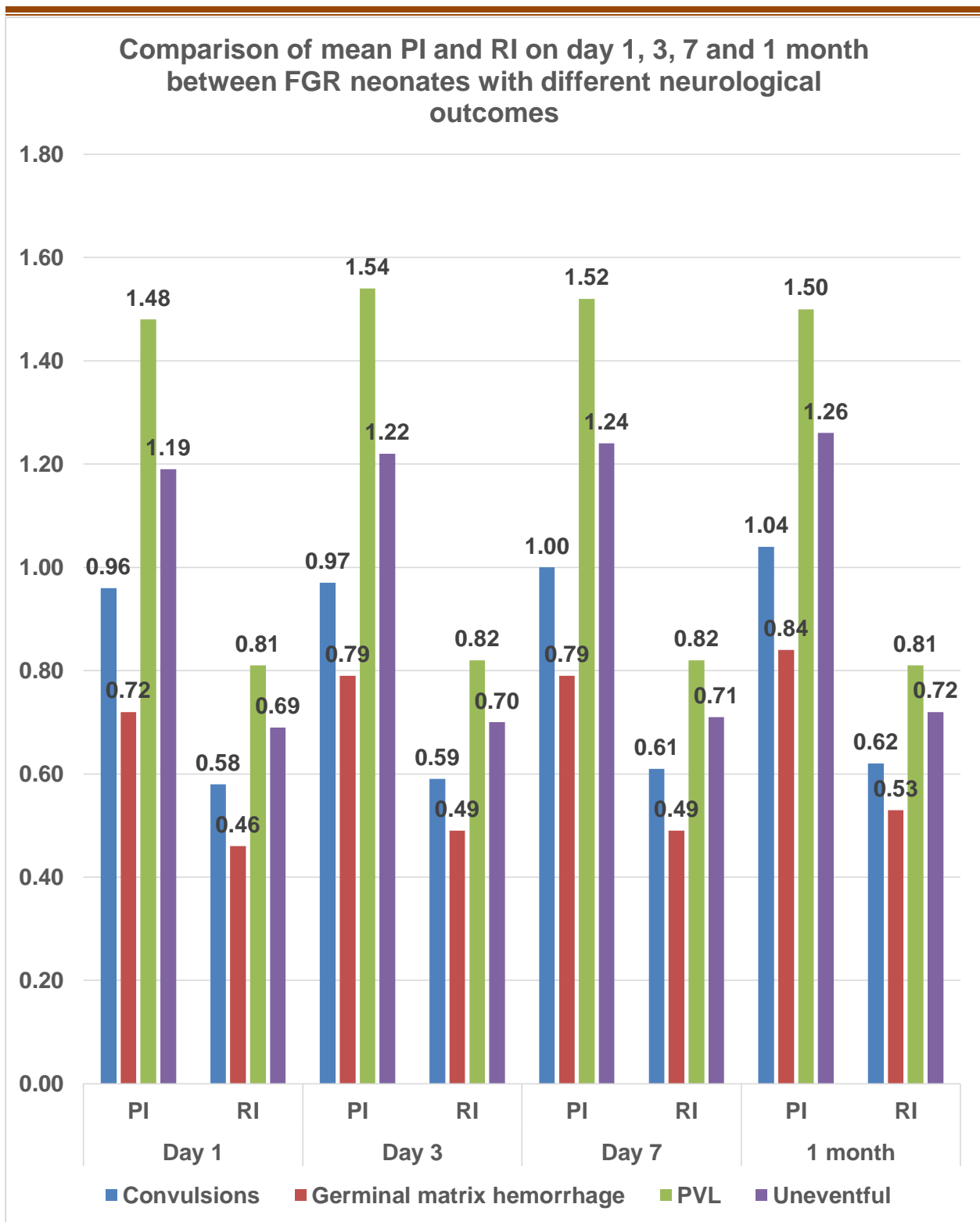


Figure 15. Bar diagram showing Comparison of mean PI and RI of MCA on day 1, 3, 7 and 1 month between FGR neonates with different neurological outcomes (n=48).

Comparison of mean MCA Doppler parameters on day 1, 3, 7 and 1 month between FGR neonates with different NICU stay duration.

Time points	Doppler parameter	NICU stay						P value*
		3 to 7 days		8 to 14 days		More than 14 days		
		Median	SD	Median	SD	Median	SD	
Day 1	PSV	30.70	3.80	33.50	5.70	34.10	3.90	0.07
	EDV	9.10	2.50	10.80	2.90	15.50	4.80	<0.01
	PI	1.22	0.15	1.15	0.16	0.90	0.25	<0.01
	RI	0.71	0.06	0.68	0.07	0.55	0.12	< 0.01
Day 3	PSV	32.10	3.60	34.10	5.50	35.11	4.25	0.13
	EDV	9.10	2.50	10.60	2.80	15.20	4.70	< 0.01
	PI	1.19	0.14	1.22	0.09	1.20	0.10	< 0.01
	RI	0.72	0.06	0.69	0.06	0.57	0.11	< 0.01
Day 7	PSV	34.10	5.20	34.82	5.50	38.10	7.10	0.34
	EDV	9.52	3.15	10.60	3.10	16.20	5.70	< 0.05
	PI	1.27	0.14	1.21	0.15	0.96	0.24	< 0.01
	RI	0.72	0.06	0.70	0.06	0.58	0.11	< 0.01
1 months	PSV	42.40	8.20	43.70	6.20	43.20	2.70	0.86
	EDV	11.40	3.50	12.60	2.50	17.60	4.20	< 0.01
	PI	1.29	0.13	1.23	0.14	0.99	0.23	< 0.01
	RI	0.73	0.05	0.71	0.06	0.59	0.10	< 0.01

*analyzed using Kruskal Wallis test

Table 12. Comparison of mean PSV, EDV, PI and RI on day 1, 3, 7 and 1 month between FGR neonates with different NICU stay duration (n=48).

A longer NICU stay was associated with higher EDV and lower PI and RI across all time points. For instance, on day 1, those with NICU stays exceeding 14 days had significantly higher EDV (15.50) and lower PI (0.90) and RI (0.55) compared to shorter stay durations, as depicted in table 12 and figures 16 and 17. These differences were statistically significant ($p < 0.01$), indicating that altered cerebral blood flow parameters may be associated with prolonged hospital stay.

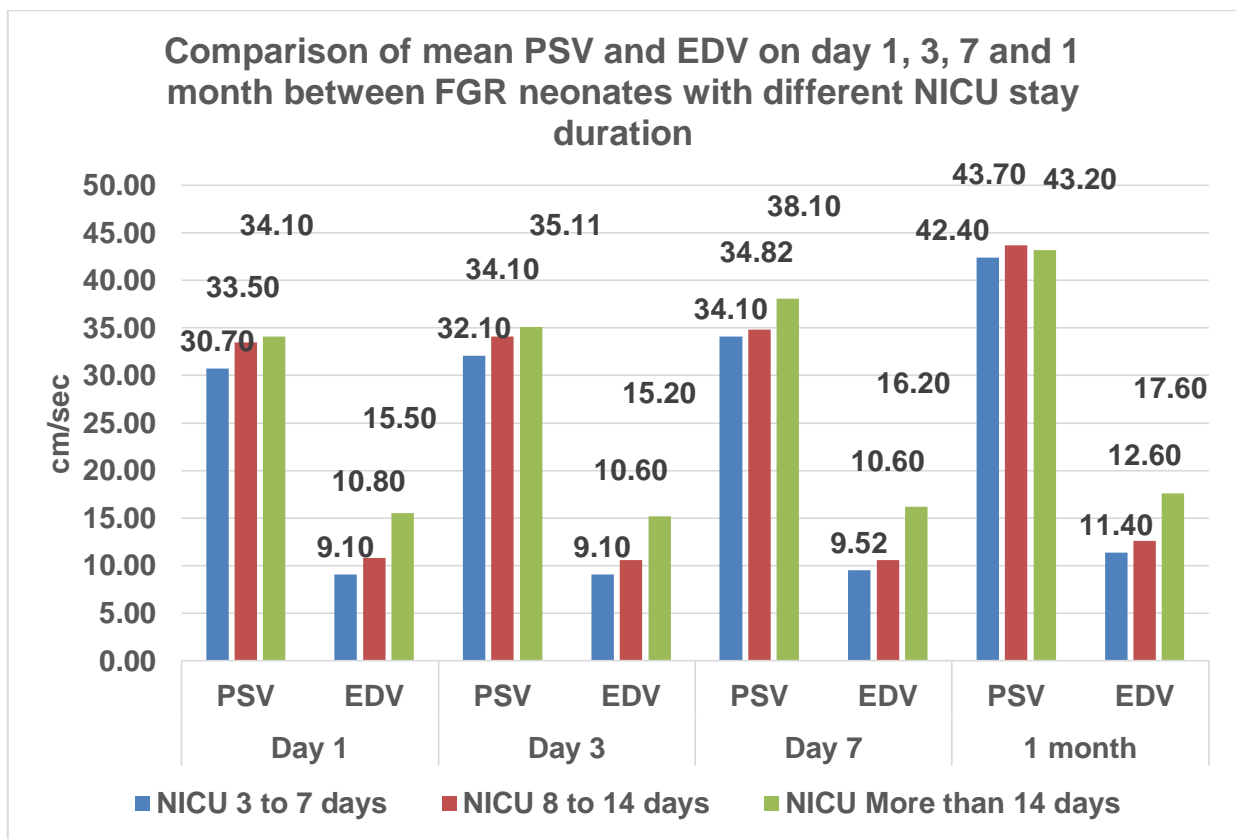


Figure 16. Bar diagram showing comparison of mean PSV, EDV of MCA on day 1, 3, 7 and 1 month between FGR neonates with different NICU stay duration (n=48)

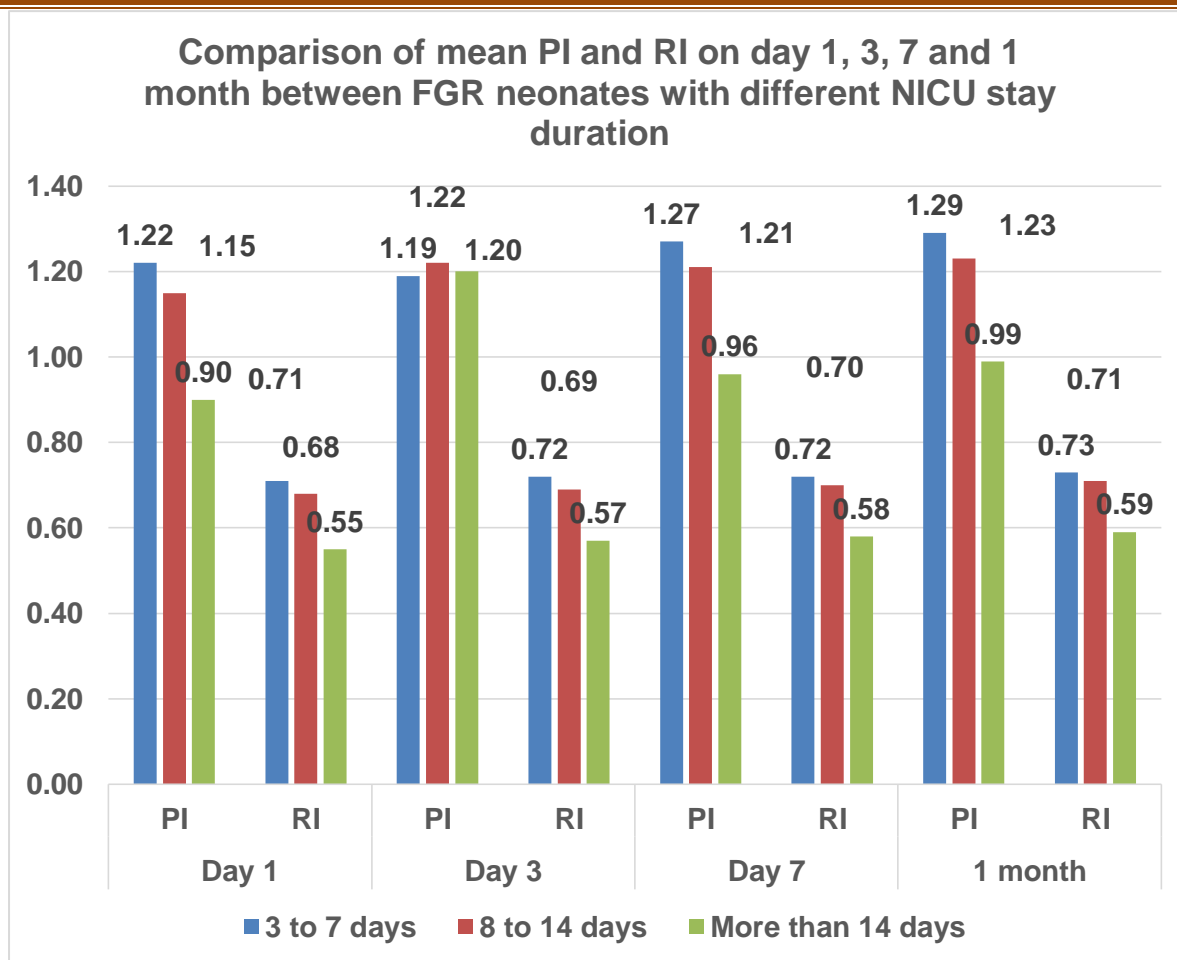


Figure 17. Bar diagram showing comparison of mean PI and RI of MCA on day 1, 3, 7 and 1 month between FGR neonates with different NICU stay duration (n=48)

Receiver operating characteristic (ROC) curves of Doppler parameters with sensitivity and specificity for predicting unfavorable CNS outcomes.

Pulsatility Index demonstrated high specificity but poor sensitivity and low AUC (< 0.4) across all time points, indicating limited standalone utility for predicting unfavorable CNS outcomes as depicted in table 13 and figure 18. Although NPV remained consistently high (~85%), the overall predictive performance was suboptimal.

Table 13. ROC curves for PI at different time points with sensitivity and specificity for predicting unfavorable CNS outcomes.

PI	PI cutoff	Sensitivity	Specificity	PPV	NPV	AUC
Day 1	1.46	13.30%	96.30%	40%	85.70%	0.28
Day 3	1.52	13.30%	100.00%	100%	86.70%	0.26
Day 7	1.52	13.30%	100.00%	100%	86.10%	0.27
1 month	1.46	20.00%	91.30%	30%	86.10%	0.36

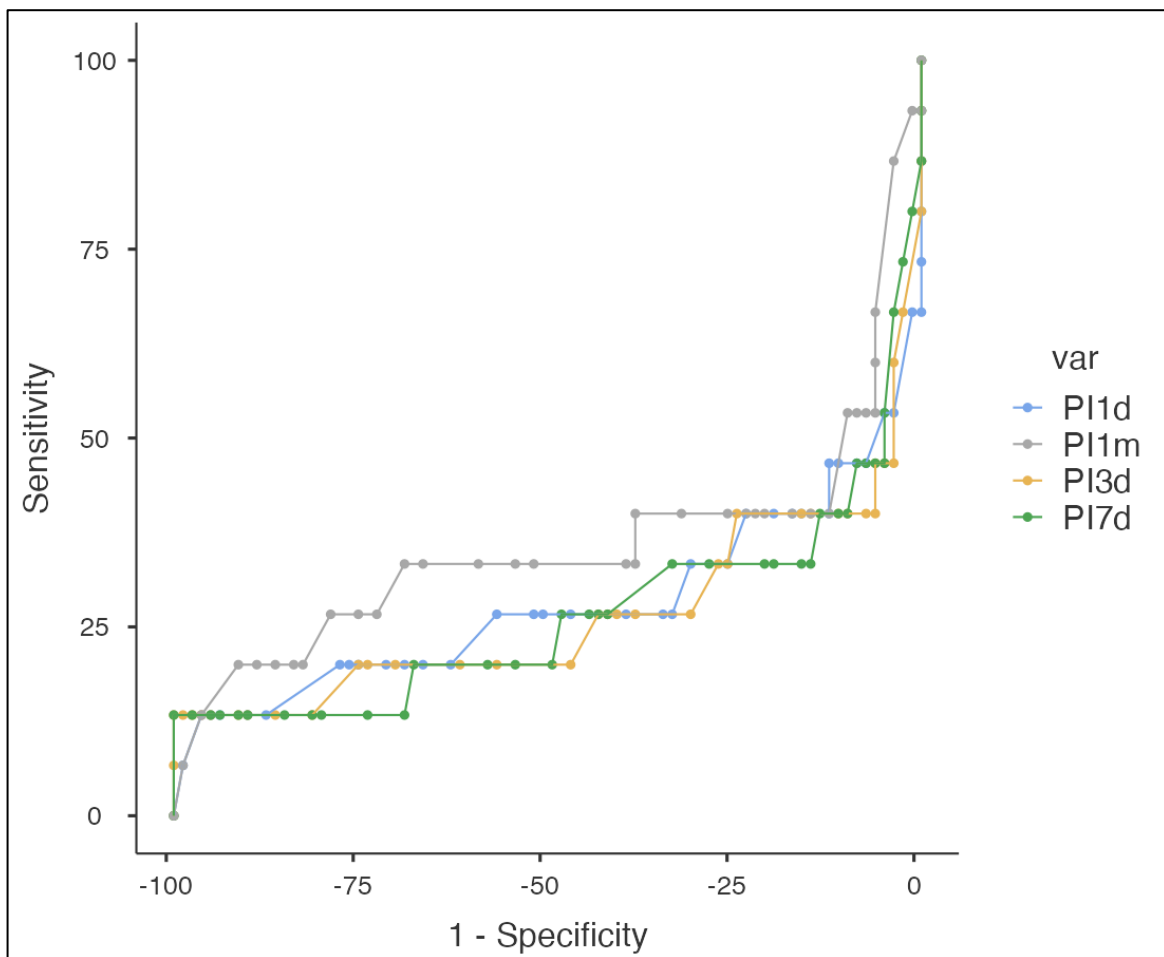


Figure 18. Receiver operating characteristic curves of PI with sensitivity and specificity for predicting unfavorable CNS outcomes.

Table 14. ROC curves for PSV at different time points with sensitivity and specificity for predicting unfavorable CNS outcomes.

PSV	PSV cutoff	Sensitivity	Specificity	PPV	NPV	AUC
Day 1	27.2	100.00%	13.50%	18%	100.00%	0.5
Day 3	35.2	46.60%	61.70%	18%	86.20%	0.5
Day 7	28.2	100.00%	9.80%	17%	100.00%	0.51
1 month	38.7	86.60%	38.20%	21%	93.30%	0.61

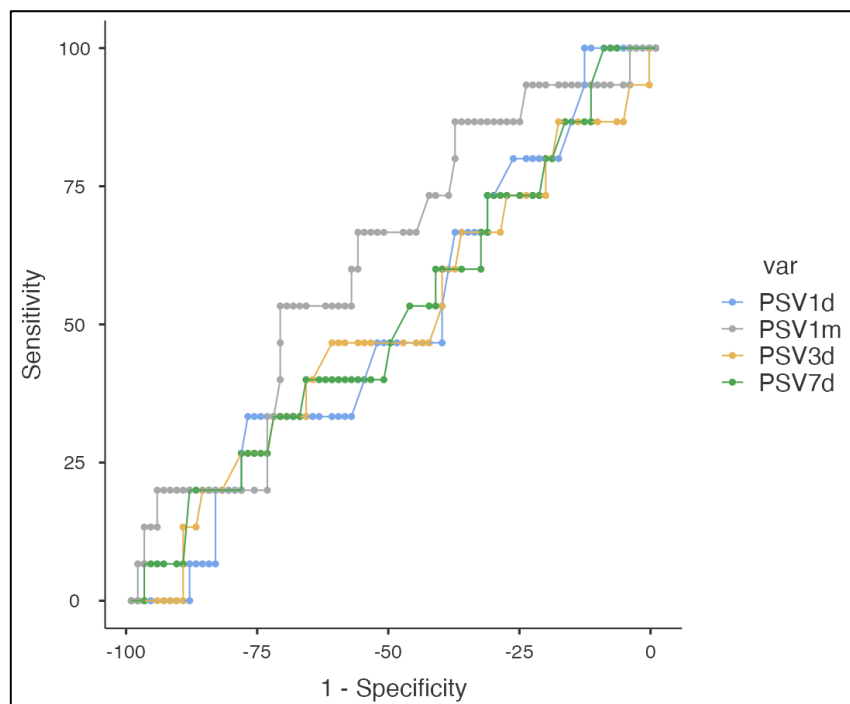


Figure 19. Receiver operating characteristic curves of PSV with sensitivity and specificity for predicting unfavorable CNS outcomes.

Peak Systolic Velocity exhibited high sensitivity and NPV, particularly at Day 1 and Day 7, but had poor specificity and low PPV as depicted in table 14 and figure 19. The overall AUC values (~ 0.5–0.6) suggest limited discriminatory power, with slight improvement at 1 month (AUC 0.61).

Table 15. ROC curves for EDV at different time points with sensitivity and specificity for predicting unfavorable CNS outcomes.

EDV	EDV cutoff	Sensitivity	Specificity	PPV	NPV	AUC
Day 1	11.1	66.60%	67.90%	28%	91.60%	0.68
Day 3	11.8	60.00%	75.30%	31%	91.10%	0.67
Day 7	10.6	80.00%	55.50%	25%	93.70%	0.68
1 month	15.5	66.60%	88.90%	53%	93.50%	0.76

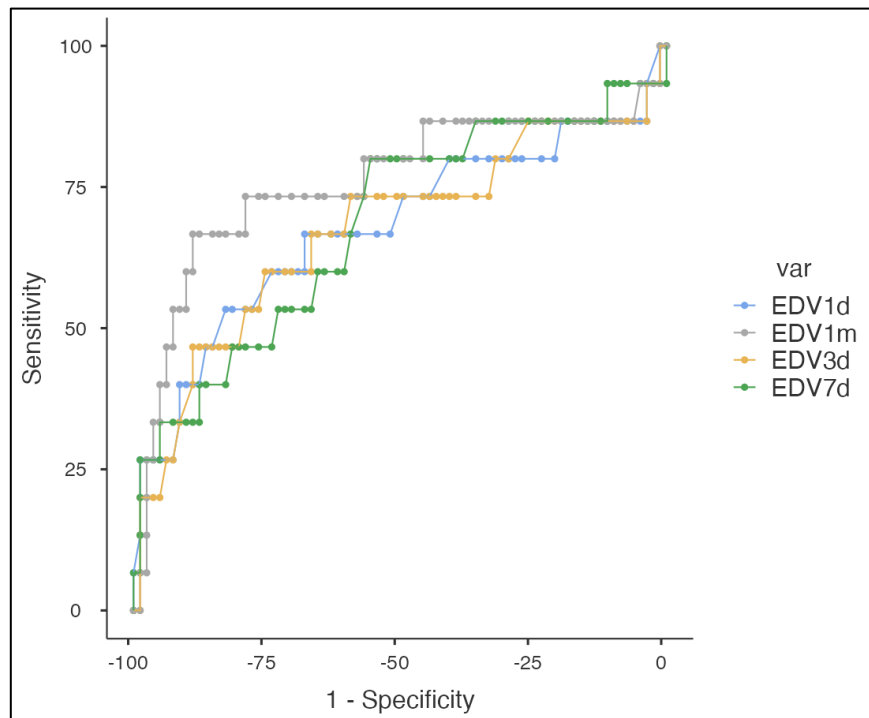


Figure 20. Receiver operating characteristic curves of EDV with sensitivity and specificity for predicting unfavorable CNS outcomes.

End Diastolic Velocity demonstrated the best overall diagnostic performance among evaluated parameters, with AUC values up to 0.76, good sensitivity and specificity, and high negative predictive value (>90%) as depicted in table 15 and figure 20. Its predictive accuracy improved notably at 1 month.

Table 16. ROC curves for RI at different time points with sensitivity and specificity for predicting unfavorable CNS outcomes.

RI	RI cutoff	Sensitivity	Specificity	PPV	NPV	AUC
Day 1	0.8	13.30%	96.30%	40%	85.70%	0.28
Day 3	0.82	13.30%	100.00%	100%	86.70%	0.27
Day 7	0.82	13.30%	100.00%	100%	86.70%	0.27
1 month	0.83	6.60%	98.70%	50%	85.10%	0.3

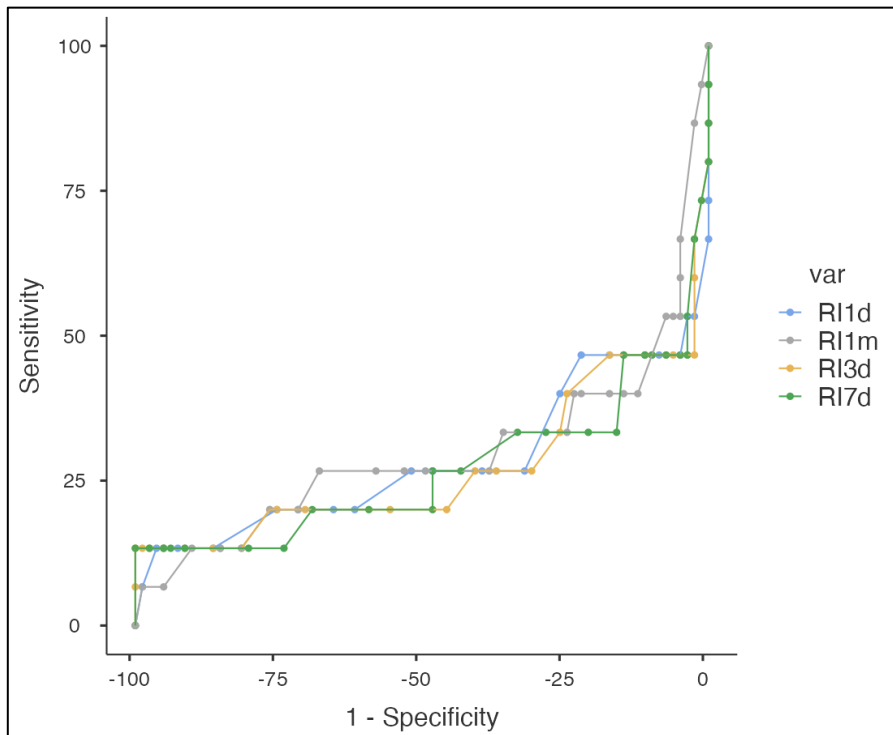


Figure 21. Receiver operating characteristic curves of RI with sensitivity and specificity for predicting unfavorable CNS outcomes.

Resistive Index demonstrated very high specificity but extremely poor sensitivity and AUC values (< 0.3) across all time points, limiting its utility as an independent predictor. Despite high negative predictive values ($\sim 85\%$), its standalone diagnostic ability was suboptimal, as depicted in table 16 and figure 21.

		Unfavorable outcome		
		Odds ratio	95% CI	p value
PSV	Day 1	0.99	0.89 to 1.11	0.94
	Day 3	0.99	0.89 to 1.11	0.81
	Day 7	1.01	0.92 to 1.11	0.82
	1 month	1.06	0.98 to 1.1	0.14
EDV	Day 1	1.25	1.07 to 1.4	< 0.01
	Day 3	1.22	1.05 to 1.4	< 0.01
	Day 7	1.2	1.05 to 1.3	< 0.01
	1 month	1.3	1.11 to 1.5	< 0.01
PI	Day 1	0.01	0 to 0.14	< 0.01
	Day 3	0.1	0 to 0.13	< 0.01
	Day 7	0.1	0 to 0.11	< 0.01
	1 month	0.02	0 to 0.5	< 0.05
RI	Day 1	0.01	0 to 0.01	< 0.01
	Day 3	0.01	0 to 0.01	< 0.01
	Day 7	0.01	0 to 0.01	< 0.01
	1 month	0.01	0 to 0.02	< 0.01

Table 17. Predictive ability of PSV, EDV, PI and RI for unfavorable CNS outcome

Predictive ability of PSV, EDV, PI and RI with odds ratio are depicted in table 17. No statistically significant association was found between PSV and unfavorable outcomes at any time point ($p>0.05$). The odds ratios were close to 1, indicating a neutral effect.

EDV showed a strong and statistically significant positive association with unfavorable outcomes across all time points ($p<0.01$). An increase in EDV corresponded to a higher risk of adverse neurological events, with odds ratios ranging from 1.20 to 1.30.

Both, PI and RI exhibited a strong inverse association with adverse outcomes, maintaining highly significant p-values throughout the study period ($p < 0.01$). RI values below normal were predictive of increased neurological risk.

CASE IMAGES:

A case of preterm FGR male neonate at day 7 shows persistent periventricular flaring adjacent to frontal horn of lateral ventricles with a tiny cyst suggestive of Grade II PVL, with Doppler parameters as shown in figure 22.

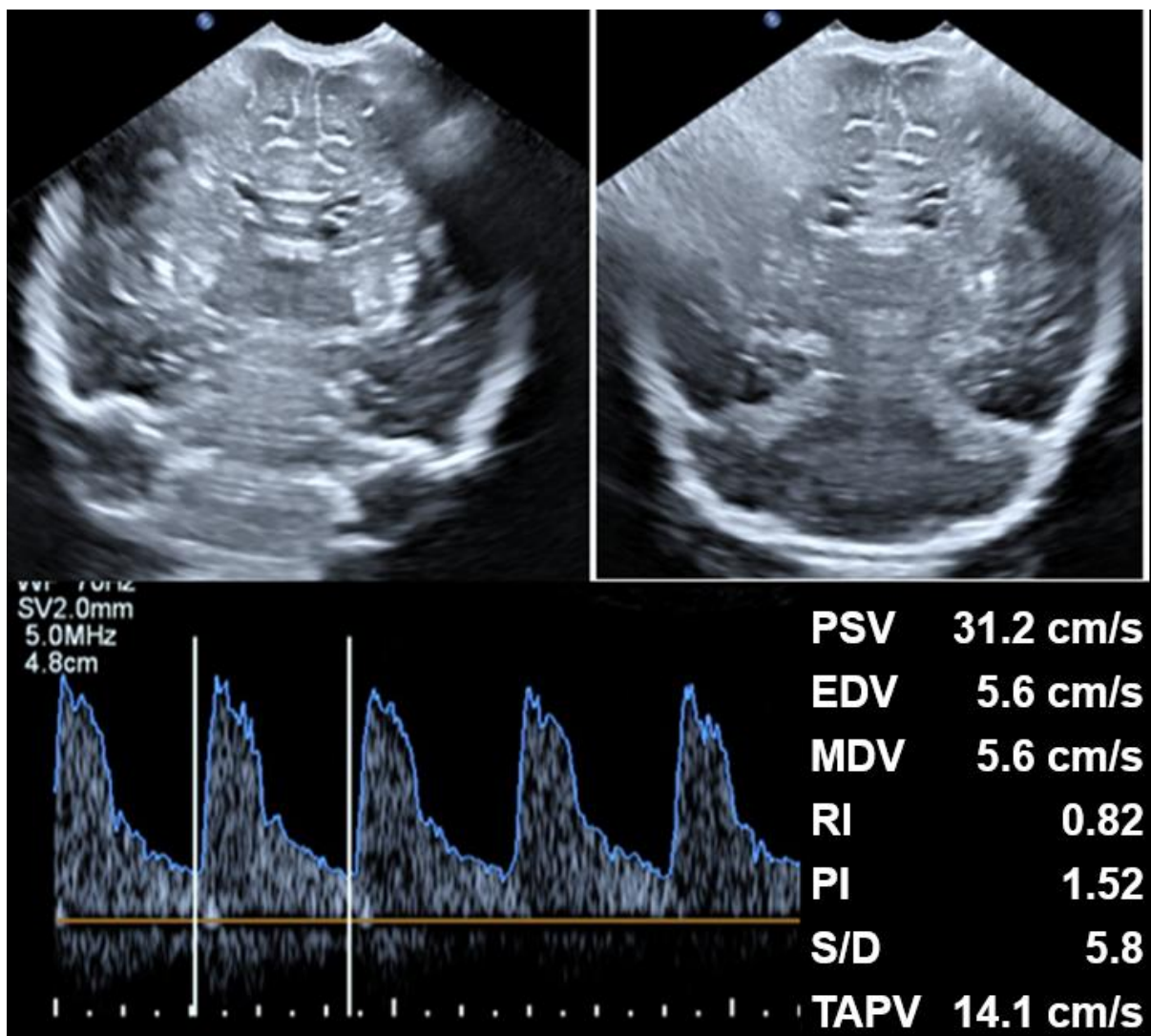


Figure 22: Neurosonogram with MCA Doppler in a preterm neonate with PVL.

A case of preterm FGR male neonate at day 3 shows germinal matrix hemorrhage in left frontal lobe, with Doppler parameters as shown in figure 23.

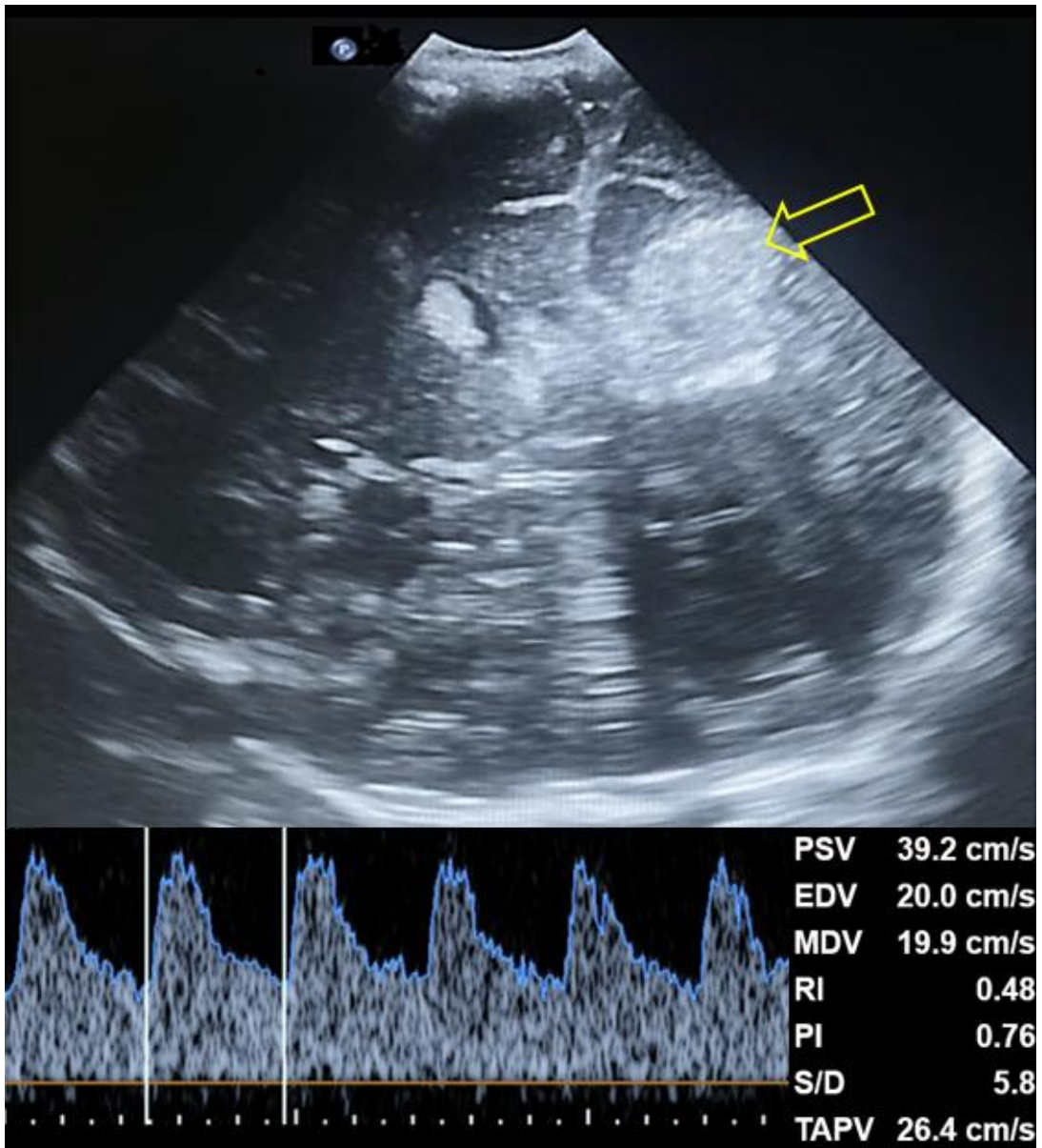


Figure 23: Neurosonogram with MCA Doppler of a preterm FGR male neonate at day 3, yellow arrow shows germinal matrix hemorrhage.

A case of term AGA female neonate at day 3 shows no significant abnormality in transcranial USG, with Doppler parameters as shown in figure 24.

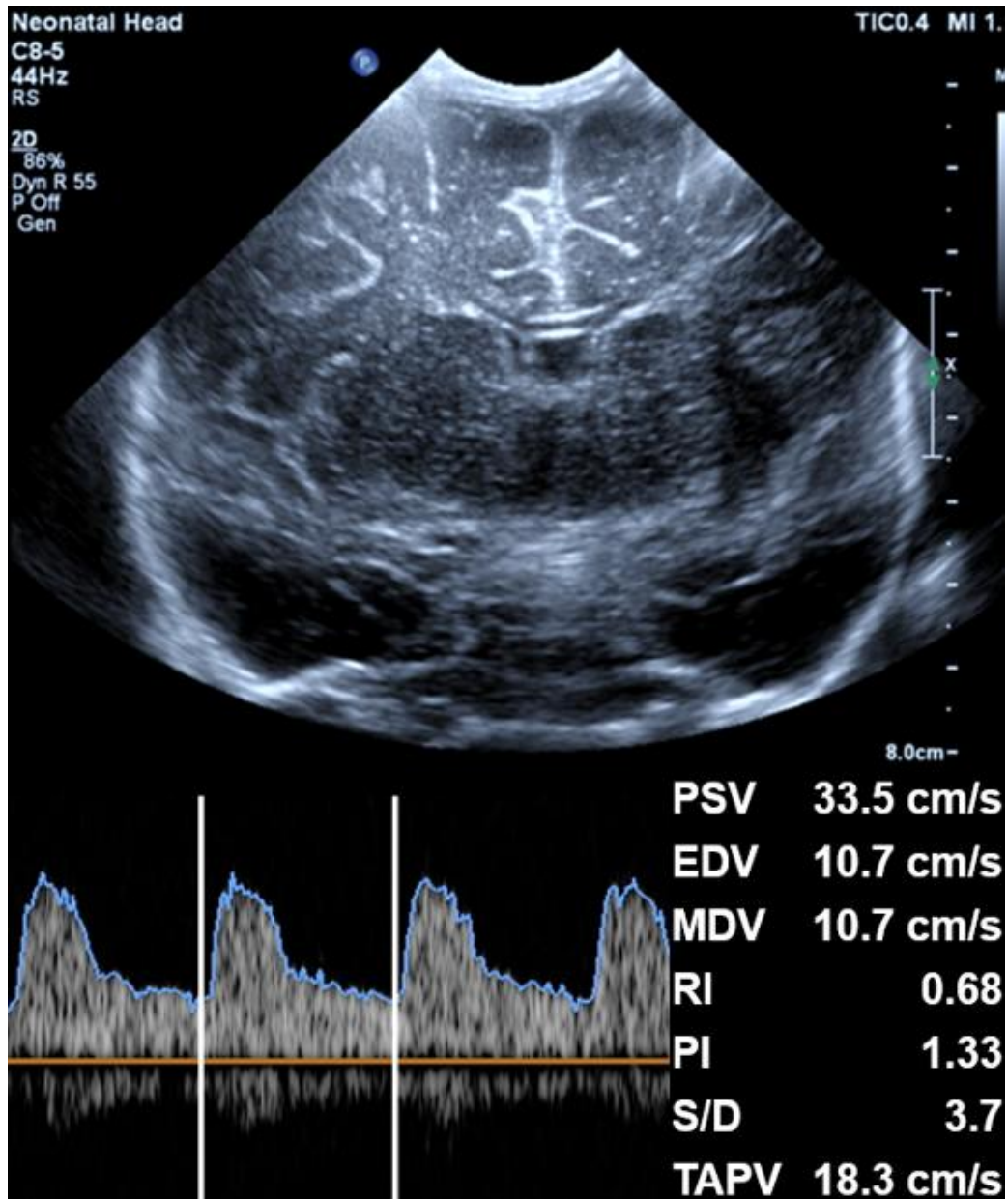


Figure 24: Neurosonogram with MCA Doppler of a Preterm AGA male neonate at day 3 shows no abnormal imaging / Doppler findings.



DISCUSSION



DISCUSSION

This cross-sectional study was conducted at Department of Radio Diagnosis and Paediatrics at R.L. Jalappa Hospital and Research Center attached to Sri Devaraj Urs Medical College, Kolar to investigate the role of the MCA doppler study indices in growth-restricted neonates. During the study, 48 FGR neonates and 48 AGA neonates were included. All neonates were subjected to cranial ultrasonography and MCA Doppler on day 1, day 3, and day 7 and 1 month with curvilinear transducer C8-5 MHz. The results of our study are discussed as follows.

Baseline characteristics

In our study, 48 neonates were included in AGA and FGR groups. Among these, 44% were female (21 in each group), and 56% were male (27 in each group), indicating a balanced distribution across the groups. In both groups, 58% of neonates were born preterm (less than 37 weeks), and 42% were born at term (between 37 to 41 weeks).

Yakout et al. also demonstrated poorer neonatal outcomes in IUGR cases, including significantly increased NICU admissions, intrauterine deaths, and low birth weights. Although APGAR scores weren't isolated, the clinical correlation is strong.⁴¹

Krishnamurthy et al. excluded neonates with 5-minute APGAR <7 to avoid confounding, so their population was inherently skewed toward higher APGARs, which may explain their lack of acute clinical events compared to our study. Jain did not discuss APGARs, but their cohort included neonates diagnosed with HIE based on Sarnat staging, indirectly implying lower scores.³⁶

Venkatesh et al. didn't use APGAR as a variable but highlighted that severely sick neonates with hemodynamic instability had extremely poor survival, indirectly supporting the importance of early poor clinical signs like low APGARs.⁴⁰

Comparison of middle cerebral artery doppler parameters between AGA and FGR

In the present study, most values across time points did not show statistically significant differences, except at 1 month, where FGR neonates had significantly higher PSV (mean 43.10) compared to AGA neonates (mean 39.90), with a p-value of <0.05 .

Jain et al. reported significantly higher PSV and EDV and lower RI/PI in HIE cases than controls. They also found that these indices varied with the severity of HIE, which aligns with our observation of abnormal Doppler values in neonates who later developed convulsions or PVL.⁴²

Yakout et al. observed that MCA PI and RI were significantly lower in IUGR cases and correlated with neonatal mortality and NICU admission. They emphasized the brain-sparing effect and cerebral vasodilation, matching our findings of decreased resistance in FGR infants.⁴¹

Krishnamurthy et al. showed that postnatal Doppler changes (notably increased EDV and reduced PI/RI) were more pronounced in FGR neonates with prior abnormal antenatal Dopplers. Their conclusion about persistent cerebral redistribution agrees with our data showing continuing Doppler abnormalities over weeks.³⁶

Venkatesh et al. focused on diastolic flow reversal as a predictor of mortality. Though our study didn't observe reversal, the strong association between lower RI and worse outcomes echoes Venkatesh's conclusion that cerebral blood flow deterioration is a predictor of poor survival.⁴⁰

Prognostic value of middle cerebral artery doppler parameters in FGR neonates

We observed that on day 1, EDV, PI, and RI were significantly different across groups, with particularly low EDV and high PI and RI seen in neonates with PVL. Similar trends were observed on subsequent days. By 1 month, neonates with PVL continued to show the lowest EDV and highest PI/RI, again with statistically significant differences ($p < 0.05$ or < 0.01 depending on the

parameter). A longer NICU stay was associated with higher EDV and lower PI and RI across all time points.

Also, in our study, Pulsatility Index demonstrated high specificity but poor sensitivity and low AUC (<0.4) across all time points, indicating limited standalone utility for predicting unfavorable CNS outcomes. Peak Systolic Velocity exhibited high sensitivity and NPV, particularly at Day 1 and Day 7, but had poor specificity and low PPV. End Diastolic Velocity demonstrated the best overall diagnostic performance among evaluated parameters, with AUC values up to 0.76, good sensitivity and specificity, and high negative predictive value (>90%). Its predictive accuracy improved notably at 1 month. Resistive Index demonstrated very high specificity but extremely poor sensitivity and AUC values (<0.3) across all time points, limiting its utility as an independent predictor.

EDV showed a strong and statistically significant positive association with unfavorable outcomes across all time points ($p<0.01$). An increase in EDV corresponded to a higher risk of adverse neurological events, with odds ratios ranging from 1.20 to 1.30. Both, PI and RI exhibited a strong inverse association with adverse outcomes, maintaining highly significant p-values throughout the study period ($p<0.01$).

Jain et al. highlighted a correlation between abnormal MCA Doppler indices and severity of HIE, indirectly implying future neurological deficits. The findings on increased EDV and decreased PI/RI match our data, especially in severely affected FGR neonates. Jain also indirectly supported our conclusions about doppler values and HINE score. They found association of lower RI/PI with more severe HIE stages, which typically carry worse developmental prognoses.⁴²

Yakout et al. didn't track specific neurological outcomes like convulsions or PVL but linked abnormal MCA PI/RI and CPR to neonatal mortality and NICU admission, which are strongly associated with poor neurodevelopment. The authors also reported increased NICU admissions among IUGR neonates and tied this to lower MCA PI and RI, in line with our data.⁴¹

Venkatesh et al. demonstrated a stark contrast in survival based on the presence of diastolic flow reversal, with dramatically reduced survival times (1.3 hours vs. 133 days), directly associating poor cerebral blood flow with fatal neurological outcomes. They emphasized RI reversal as an indication of mortality, a stage well beyond what would be assessed on HINE scoring, but in a compatible trajectory of worsening cerebral function.⁴⁰

Krishnamurthy et al. identified cranial ultrasound abnormalities (CUAs) in 20% of FGR neonates with abnormal MCA Dopplers, including PVL and subdural hemorrhages, which closely mirrors our group's adverse neurological outcomes in the same population. They also found that FGR neonates with persistent abnormal cerebral blood flow postnatally required more intensive care, suggesting a link between Doppler profiles and NICU needs, though their data didn't break NICU stay into durations. The authors observed that postnatal MCA Doppler abnormalities persist in FGR neonates and may signal a higher risk of neuro-disability.³⁶

A recent review by Kumar's suggested that low EDV and elevated RI/PI are linked to poor neurological outcomes. They also note a sustained reduction in CBF velocities in all major arteries up to 1–2 months in such cases and recommended serial monitoring rather than relying on a single Doppler parameter and stresses the need for combined clinical and imaging predictors to improve prognostication.²⁶

Reversal of RI and Absent End Diastolic Doppler wave form

One of the study objectives was to evaluate whether reversal or absence of end-diastolic flow in the middle cerebral artery (MCA) could serve as an early marker of neonatal mortality and neurological morbidity.

In our study, two FGR neonates demonstrated reversed end-diastolic flow in the MCA during Doppler assessments performed on Day 1 and Day 3 of life, respectively. Both neonates subsequently succumbed with no followed-up Day 10 and 1 month of life Doppler parameters, therefore were excluded from the final analysis dataset.

The early postnatal detection of reversed end-diastolic flow in these neonates highlights the prognostic significance of this Doppler finding. These observations are consistent with the findings of Venkatesh et al. who reported a strong association between MCA diastolic flow reversal and drastically reduced neonatal survival, with a mean survival time of only 1.3 hours following reversal detection.⁴⁰

Although reversal events were rare in our study population, their occurrence was uniformly associated with mortality, thereby reinforcing the concept that absent or reversed end-diastolic flow in the MCA postnatally is a critical and ominous predictor of adverse outcomes.

Given the fatal progression observed in both cases with reversed flow, it is suggested that serial cerebral Doppler surveillance in high-risk neonates, particularly those with FGR, could offer an important opportunity for early identification of critically compromised neonates.

SUMMARY



SUMMARY

This cross-sectional study was conducted at Department of Radio Diagnosis and Pediatrics at R.L. Jalappa Hospital and Research Center attached to Sri Devaraj Urs Medical College, Kolar to investigate the role of the MCA Doppler study indices in growth-restricted neonates. During the study, 48 FGR neonates and 48 AGA neonates were included. All neonates were subjected to cranial ultrasonography and MCA Doppler on day 1, day 3, and day 7 and 1 month with curvilinear transducer C8-5 MHz.

In our study, 48 neonates were included in AGA and FGR groups. Among these, 44% were female (21 in each group), and 56% were male (27 in each group), indicating a balanced distribution across the groups. In both groups, 58% of neonates were born preterm (less than 37 weeks), and 42% were born at term (between 37 to 41 weeks).

Most values across time points did not show statistically significant differences, except at 1 month, where FGR neonates had significantly higher PSV (mean 43.10) compared to AGA neonates (mean 39.90), with a p-value of <0.05 .

On day 1, EDV, PI, and RI were significantly different across groups, with particularly low EDV and high PI and RI seen in neonates with PVL. Similar trends were observed on subsequent days. By 1 month, neonates with PVL continued to show the lowest EDV and highest PI/RI, again with statistically significant differences ($p < 0.05$ or < 0.01 depending on the parameter).

A longer NICU stay was associated with higher EDV and lower PI and RI across all time points. For instance, on day 1, those with NICU stays exceeding 14 days had significantly higher EDV (15.50) and lower PI (0.90) and RI (0.55) compared to shorter stay durations.

Pulsatility Index demonstrated high specificity but poor sensitivity and low AUC (<0.4) across all time points, indicating limited standalone utility for predicting unfavorable CNS outcomes. Peak Systolic Velocity exhibited high sensitivity and NPV, particularly at Day 1 and Day 7, but had poor specificity and low PPV. End Diastolic Velocity demonstrated the best overall diagnostic performance among evaluated parameters, with AUC values up to 0.76, good sensitivity and specificity, and high negative predictive value (>90%). Its predictive accuracy improved notably at 1 month. Resistive Index demonstrated very high specificity but extremely poor sensitivity and AUC values (<0.3) across all time points, limiting its utility as an independent predictor.

EDV showed a strong and statistically significant positive association with unfavorable outcomes across all time points ($p<0.01$). An increase in EDV corresponded to a higher risk of adverse neurological events, with odds ratios ranging from 1.20 to 1.30. Both, PI and RI exhibited a strong inverse association with adverse outcomes, maintaining highly significant p-values throughout the study period ($p<0.01$).

LIMITATIONS



LIMITATIONS

There are a few limitations of the present study:

1. Being conducted in a single institution restricts the external validity of our findings. Variations in clinical protocols, NICU care, Doppler technique, and follow-up procedures across centers could influence cerebral hemodynamics and outcomes.
2. Although we followed neonates up to 1 month with follow-up Doppler, many neurological deficits (especially cognitive or behavioral) may manifest later in infancy or early childhood.
3. NICU duration is influenced by multiple factors, which may have introduced variability in our findings; future multicenter cohort studies are needed to validate these results.
4. Doppler measurements, particularly in neonates, are operator-dependent and prone to variability based on insonation angle, probe pressure, and patient movement.

CONCLUSION

A decorative graphic consisting of a thick black horizontal line and a thick black vertical line intersecting at a right angle. The vertical line is positioned to the right of the word 'CONCLUSION', and the horizontal line is positioned below it. The intersection point is to the right of the word.

CONCLUSION

Based on the results of our study, we can conclude that:

1. Key MCA Doppler findings in FGR neonates included increased end-diastolic velocity (EDV), decreased pulsatility index (PI) and decreased resistance index (RI).
2. End Diastolic Velocity (EDV) was found to be the most reliable and diagnostically accurate Doppler parameter for predicting unfavorable central nervous system (CNS) outcomes. It showed good sensitivity, specificity, and a relatively high area under the curve (AUC up to 0.76), particularly improving at 1 month.
3. Prolonged NICU stay in FGR neonates was linked to abnormal cerebral Doppler parameters, especially lower PI and RI.

RECOMMENDATIONS



RECOMMENDATIONS

Thus, it is recommended that:

1. Serial postnatal cerebral Doppler assessments (especially of the middle cerebral artery) should be incorporated into routine evaluation protocols for neonates with Fetal Growth Restriction (FGR).
2. Doppler indices (PI, RI, and EDV) should be used as early screening tools to identify FGR neonates at risk of adverse neurological outcomes
3. Future multicenter cohorts with long term follow up into early childhood should be done for greater generalizability.

BIBLIOGRAPHY

A decorative graphic consisting of a vertical brown line and a horizontal black line intersecting at a right angle, positioned to the right of the word 'BIBLIOGRAPHY'.

BIBLIOGRAPHY

1. Malhotra A, Allison BJ, Castillo-Melendez M, Jenkin G, Polglase GR, Miller SL. Neonatal Morbidities of Fetal Growth Restriction: Pathophysiology and Impact. *Front Endocrinol.* 2019;10:55.
2. Wixey J, Bjorkman S. Improving brain outcomes in the growth restricted newborn: treating after birth. *Neural Regen Res.* 2021;16(5):978.
3. Sharma D, Farahbakhsh N, Shastri S, Sharma P. Intrauterine growth restriction - part 2. *J Matern-Fetal Neonatal Med Off J Eur Assoc Perinat Med Fed Asia Ocean Perinat Soc Int Soc Perinat Obstet.* 2016;29:4037–48.
4. Gonçalves FG, Hwang M. Superficial anatomy of the neonatal cerebrum — an ultrasonographic roadmap. *Pediatr Radiol.* 2021;51(3):353–70.
5. D'Andrea A, Conte M, Scarafile R, Riegler L, Cocchia R, Pezzullo E, et al. Transcranial Doppler ultrasound: Physical principles and principal applications in Neurocritical care unit. *J Cardiovasc Echography.* 2016;26(2):28.
6. Cohen E, Baerts W, Bel F van. Brain-Sparing in Intrauterine Growth Restriction: Considerations for the Neonatologist. *Neonatology.* 2015;108(4):269–76.
7. Rhee CJ, Costa CS da, Austin T, Brady KM, Czosnyka M, Lee JK. Neonatal cerebrovascular autoregulation. *Pediatric Research.* 2018;84(5):602–10.
8. Epelman M, Daneman A, Chauvin N, Hirsch W. Head Ultrasound and MR Imaging in the Evaluation of Neonatal Encephalopathy: Competitive or Complementary Imaging Studies? *Magnetic Resonance Imaging Clinics of North America.* 2012;20(1):93–115.
9. Camfferman FA, Goederen R de, Govaert P, Dudink J, Bel F van, Pellicer A, et al. Diagnostic and predictive value of Doppler ultrasound for evaluation of the brain circulation in preterm infants: a systematic review. *Pediatric Research.* 2020;87(S1):50–8.
10. Gerner GJ, Burton VJ, Poretti A, Bosemani T, Cristofalo E, Tekes A, et al. Transfontanellar duplex brain ultrasonography resistive indices as a prognostic tool in neonatal hypoxic-ischemic encephalopathy before and after treatment with therapeutic hypothermia. *Journal of Perinatology.* 2016;36(3):202–6.
11. 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. *Pediatric Research.* 2017;82(2):184–93.

-
12. Powles AEJ, Martin DJ, Wells ITP, Goodwin CR. Physics of ultrasound. *Anaesthesia & Intensive Care Medicine*. 2018;19(4):202–5.
 13. Verlhac S. Transcranial Doppler in children. *Pediatr Radiol*. 2011;41(S1):153–65.
 14. Horsch S, Schwarz S, Arnaez J, Steggerda S, Arena R, Govaert P, et al. Cerebral Doppler imaging in neonates: A guide for clinical application and diagnosis. *Develop Med Child Neuro*. 2024;66(12):1570–89.
 15. Richer EJ, Riedesel EL, Linam LE. Review of Neonatal and Infant Cranial US. *RadioGraphics*. 2021;41(7):E206–7.
 16. Lee AC, Katz J, Blencowe H, Cousens S, Kozuki N, Vogel JP, et al. National and regional estimates of term and preterm babies born small for gestational age in 138 low-income and middle-income countries in 2010. *The Lancet Global Health*. 2013;1(1):e26–36.
 17. Lee AC, Kozuki N, Cousens S, Stevens GA, Blencowe H, Silveira MF, et al. Estimates of burden and consequences of infants born small for gestational age in low and middle income countries with INTERGROWTH-21st standard: analysis of CHERG datasets. *BMJ*. 2017;j3677.
 18. Lifam A, Malagi NAN, Thobbi AN. Study on clinical profile, risk factors, morbidity and mortality patterns of intrauterine growth restricted babies admitted in neonatal intensive care unit of tertiary care hospital, Vijayapura. *Int J Contemp Pediatr*. 2024;11:1357–64.
 19. Murki S. Intrauterine Growth Retardation - A Review Article. *Journal of Neonatal Biology*. 2014;03(03).
 20. Suhag A, Berghella V. Intrauterine Growth Restriction (IUGR): Etiology and Diagnosis. *Curr Obstet Gynecol Rep*. 2013;2:102–11.
 21. Sovio U, White IR, Dacey A, Pasupathy D, Smith GCS. Screening for fetal growth restriction with universal third trimester ultrasonography in nulliparous women in the Pregnancy Outcome Prediction (POP) study: a prospective cohort study. *The Lancet*. 2015;386(10008):2089–97.
 22. Adebami OJ, Owa JA. Comparison between CANSORE and other anthropometric indicators in fetal malnutrition. *The Indian Journal of Pediatrics*. 2008;75(5):439–42.
 23. Sharma D, Shastri S, Sharma P. Intrauterine Growth Restriction: Antenatal and Postnatal Aspects. *Clinical Medicine Insights: Pediatrics*. 2016;10:67-83.
 24. Powers WJ. Cerebral Blood Flow and Metabolism. In: *Stroke*. Elsevier; 2016; e7. p. 28-46.
 25. Wang S, Tang C, Liu Y, Border JJ, Roman RJ, Fan F. Impact of impaired cerebral blood flow autoregulation on cognitive impairment. *Front Aging*. 2022;3:1077302.
-

-
26. Kumar G, Patodia J, Suryawanshi P, Maheshwari A, Padhan NC. Transcranial Doppler: A New Stethoscope–Voiceover Tool for Neonatal Brain. *Newborn*. 2024;2(4):279–90.
 27. Thakur A, Jain P, Modi M, Singh A, Kansal B, Kler N. Normative Values of Cerebral Blood Flow Velocities in Very Low Birth Weight Neonates During First 28 Days of Life. *Indian Pediatr*. 2024;61(9):835–8.
 28. Beuchée A, Pladys P, Senhadji L, Bétrémieux P, Carré F. Beat-to-beat blood pressure variability and patent ductus arteriosus in ventilated, premature infants. *Pflugers Arch - Eur J Physiol*. 2003;446(2):154–60.
 29. Milona E, Rallis D, Mitsiakos G, Goutsiou E, Hatzioannidis E, Tsakalidis C, et al. Evaluation of cerebral oxygenation and perfusion in small for gestational age neonates and neurodevelopmental outcome at 24–36 months of age. *Journal of Perinatal Medicine*. 2020;48(3):280–8.
 30. Floyd TF, Clark JM, Gelfand R, Detre JA, Ratcliffe S, Guvakov D, et al. Independent cerebral vasoconstrictive effects of hyperoxia and accompanying arterial hypocapnia at 1 ATA. *Journal of Applied Physiology*. 2003;95(6):2453–61.
 31. Trejo-Soto C, Hernández-Machado A. Normalization of Blood Viscosity According to the Hematocrit and the Shear Rate. *Micromachines*. 2022;13(3):357.
 32. Hernandez-Andrade E, Stampalija T, Figueras F. Cerebral blood flow studies in the diagnosis and management of intrauterine growth restriction. *Current Opinion in Obstetrics & Gynecology*. 2013;25(2):138–44.
 33. Berkley E, Chauhan SP, Abuhamad A. Doppler assessment of the fetus with intrauterine growth restriction. *American Journal of Obstetrics and Gynecology*. 2012;206(4):300–8.
 34. Khalil A, Morales-Rosello J, Khan N, Nath M, Agarwal P, Bhide A, et al. Is cerebroplacental ratio a marker of impaired fetal growth velocity and adverse pregnancy outcome? *American Journal of Obstetrics and Gynecology*. 2017;216(6):606.e1-606.e10.
 35. Bonnevier A, Maršál K, Brodzki J, Thuring A, Källén K. Cerebroplacental ratio as predictor of adverse perinatal outcome in the third trimester. *Acta Obstet Gynecol Scand*. 2021;100(3):497–503.
 36. Krishnamurthy MB, Pharande P, Whiteley G, Hodges RJ, Malhotra A. Postnatal middle cerebral artery Dopplers in growth-restricted neonates. *European Journal of Pediatrics*. 2020;179(4):571–7.
 37. Vik SD, Torp H, Follestad T, Støen R, Nytnes SA. NeoDoppler: New ultrasound technology for continuous cerebral circulation monitoring in neonates. *Pediatr Res*. 2020;87(1):95–103.

-
38. Aliefendioglu D, Ylmaz S, Misirlioglu ED, Sayg S, Ozdogan S, Kocak U. Do Cerebral Blood Flow Velocities Change in Iron Deficiency Anemia? *Journal of Pediatric Hematology/Oncology*. 2007;29(11):747–51.
 39. Fukuda S, Kato T, Kakita H, Yamada Y, Hussein MH, Kato I, et al. Hemodynamics of the Cerebral Arteries of Infants With Periventricular Leukomalacia. *Pediatrics*. 2006;117(1):1–8.
 40. Venkatesh I, Shubha HV, Karthik N, RaviShankar S. A Study of reversal of diastolic blood flow in the middle cerebral artery using doppler ultrasound in the prognostication in sick neonates. *Journal of Clinical Neonatology*. 2020;9(1):52.
 41. Yakout AAESAS, Zakaria AEMM, Saeed AM. Role of middle cerebral artery and ductus venosus doppler in evaluation of intrauterine growth restriction. *Al-Azhar Medical Journal*. 2021;50(2):1047–58.
 42. Jain S, Jain P. Role of cerebral artery Doppler velocimetry in neonatal hypoxic ischemic encephalopathy. *International Journal of Contemporary Pediatrics*. 2022;9(5):462.
 43. Machin D, Campbell MJ, Tan SB, Tan SH. *Sample Sizes for Clinical, Laboratory and Epidemiology Studies*. 4th ed. Wiley-Blackwell; 2018. p. 10-69.

ANNEXURE



ANNEXURE I - PROFORMA

**STUDY TITLE: “ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER
IN POSTNATAL GROWTH RESTRICTED NEONATES – A CASE CONTROL STUDY.”**

DEMOGRAPHIC DETAILS

1. Name:
2. Age:
3. UHID No / IP No:
4. Parent / Guardian name:
5. Relation to child:

MATERNAL DETAILS

1. Maternal age:
2. Nulliparous / multiparous:
3. Smoking / drug abuse:
4. BMI:
5. Any maternal conditions: Diabetes / hypertension
6. Any maternal comorbidities:
7. Gestation age at delivery:
8. Abnormal fetal growth measurements (diagnostic for fetal growth restriction): Present / Absent
9. Abnormal Doppler findings (diagnostic for fetal growth restriction): Present / Absent.

CHILD DETAILS

1. Birth weight:
2. 5 min APGAR:
3. Neonatal co-morbidities:
4. Resuscitation: YES / NO

NEUROSONOGRAM FINDINGS:

Normal / unfavorable (any pathology)

MIDDLE CEREBRAL ARTERY DOPPLER FINDINGS:

DOPPLER PARAMETERS	Day 1	Day 3	Day 7	1 month
PSV				
EDV				
PI				
RI				

PSV : Peak systolic velocity

EDV : End diastolic velocity

PI : Pulsatility index = $\frac{PSV-EDV}{\text{Mean velocity}}$

RI : Resistive index = $\frac{PSV-EDV}{PSV}$

ADVERSE NEUROLOGICAL OUTCOME: Yes / No

1. Germinal matrix hemorrhage (GMH) / Intraventricular Hemorrhage (IVH)
2. Periventricular leukomalacia (PVL)
3. Convulsions in first 10 days related to neurological cause

ANNEXURE II - INFORMED CONSENT

I Mr/Mrs. _____ parent / guardian of _____ have been explained in my own understandable language, that my child will be included in a study which is **“ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN POSTNATAL GROWTH RESTRICTED NEONATES - A CASE CONTROL STUDY”**.

- a. I have been explained that my child’s clinical findings, investigations, postoperative findings will be assessed and documented for study purpose.
- b. I have been explained my child’s participation in this study is entirely voluntary, and I can withdraw my child from the study any time and this will not affect my relation with my doctor or the treatment for my child’s ailment.
- c. I have been explained about the interventions needed possible benefits and adversities due to interventions, in my own understandable language.
- d. I have understood that all my child’s details found during the study are kept confidential and while publishing or sharing of the findings, my child’s details will be masked.
- e. I have principal investigator mobile number for enquiries.
- f. I in my sound mind give full consent for my child to be added in the part of this study.

Signature of the parent/guardian:

Signature of the witness:

Name:

Name:

Relation to patient:

Relation to patient:

Date:

Place:

ANNEXURE III - PATIENT INFORMATION SHEET

STUDY TITLE: “**ROLE OF MIDDLE CEREBRAL ARTERY DOPPLER IN POSTNATAL GROWTH RESTRICTED NEONATES - A CASE CONTROL STUDY**”.

STUDY SITE: R.L Jalappa Hospital and Research Centre, Tamaka, Kolar.

This is to inform you that, your child require MCA Doppler scan for assessment and monitoring of cerebral blood flow. This USG can be used as a prognostic marker for neonatal adverse outcomes and for planning of the clinical management. The neonates referred to department of Radiology at R.L Jalappa hospital and research Centre, Tamaka, Kolar to undergo Neurosonogram & MCA Doppler as a part of protocol and of those patients who meet the inclusion criteria will be taken for the study.

We are conducting this study MCA Doppler parameters to predict the severity and outcome of neurological condition.

If you are willing your child will be enrolled in this study and we will do USG and other relevant investigations which are required for further management. This will facilitate evaluation of middle cerebral artery Doppler parameters, which can be used for predicting adverse neurological outcomes in FGR neonates and planning clinical management. It will also benefit other FGR neonates in the future.

You are free to opt-out of the study at any time if you are not satisfied or apprehensive to be a part of the study. Your child’s treatment and care will not be compromised if you refuse to be a part of the study.

The study will not add any risk or financial burden to you if you are part of the study. In case of any complications patient will be treated accordingly.

Your and your child’s identity and clinical details will be confidential and will be used only for research purpose.

You are free to contact principal investigator for any doubt or clarification you have.

Principal investigator: Dr. Thavan Mummaneni

Mobile no: 8500654206

Date:

MASTER CHART



KEY TO MASTER CHART

1. **S.No.:** serial number
2. **F:** Female
3. **M:** male
4. **LBW:** Low birth weight
5. **POG:** Period of gestation
6. **W:** Weeks
7. **D:** Day / Days
8. **M:** Month
9. **AGA:** Appropriate gestation age neonates.
10. **FGR:** Fetal growth restricted neonates
11. **NICU:** Neonatal intensive care unit
12. **PSV:** Peak systolic velocity
13. **EDV:** End diastolic velocity
14. **PI:** Pulsatility index
15. **RI:** Resistive index
16. **U:** Uneventful
17. **C:** convulsions
18. **GMH:** Germinal matrix hemorrhage
19. **PVL:** Periventricular leukomalacia
20. **A:** Absent

S. No.	BABY GENDER	BABY WEIGHT (KG)	LBW	5 MIN APGAR SCORE	POG	AGA / FGR	NICU STAY	PSV-1 D	EDV-1 D	PI-1 D	RI-1 D	PSV-3 D	EDV-3 D	PI-3 D	RI-3 D	PSV-7 D	EDV-7 D	PI-7 D	RI-7 D	PSV-1 M	EDV-1 M	PI-1 M	RI-1 M	EVENTS	NEUROLOGIC AL OUTCOME	RO-RI
1	F	1.8	Yes	8	37W 5 D	FGR	7	27.4	9	1.04	0.67	28.2	9	1.16	0.68	27.5	9.1	1.14	0.67	29.5	9.1	1.19	0.69	U	No	A
2	M	1.2	Yes	7	35 W	FGR	6	24.2	6.8	1.25	0.72	29.6	8	1.28	0.73	33.5	8.7	1.31	0.74	31.8	7.6	1.36	0.76	U	No	A
3	M	1.4	Yes	8	38 W	FGR	9	33.5	9.7	1.23	0.71	34.2	9.6	1.25	0.72	36.2	9.8	1.28	0.73	36.6	10.6	1.23	0.71	U	No	A
4	M	1.4	Yes	8	36 W 5 D	FGR	21	38.2	19.9	0.76	0.48	40.2	20.1	0.8	0.5	44	21.1	0.83	0.52	45.4	20.4	0.89	0.55	C	Yes	A
5	M	1.9	Yes	7	39W 4 D	FGR	3	26.5	8.2	1.18	0.69	28.2	8.2	1.23	0.71	28	8.4	1.21	0.7	32.1	10	1.18	0.69	U	No	A
6	F	1.1	Yes	9	34 W	FGR	10	35.2	8.8	1.33	0.75	33	7.9	1.36	0.76	35	8.1	1.38	0.77	43.9	11	1.33	0.75	U	No	A
7	F	2.3	Yes	7	39 W 1 D	FGR	7	33	11.6	1.09	0.65	36.6	13.2	1.07	0.64	40.1	14.8	1.05	0.63	41.7	14.6	1.09	0.65	U	No	A
8	M	1.6	Yes	7	35 W	FGR	8	31.2	11.2	0.91	0.64	36.2	12.7	1.09	0.65	39.2	13.3	1.12	0.66	35.5	12.8	1.07	0.64	U	No	A
9	M	1.3	Yes	7	37 W 4 D	FGR	18	40.5	19.4	0.83	0.52	40.5	19	0.85	0.53	42	19.3	0.87	0.54	46.2	20.8	0.89	0.55	C	Yes	A
10	M	1.2	Yes	8	34 W 4 D	FGR	8	45.2	16.3	1.07	0.64	45.2	15.8	1.09	0.65	42.5	14	1.14	0.67	41.1	11.9	1.23	0.71	U	No	A
11	M	1.8	Yes	10	37 W 4 D	FGR	5	32.5	8.1	1.33	0.75	34.5	7.9	1.38	0.77	30.2	6.6	1.41	0.78	34.5	7.2	1.44	0.79	U	No	A
12	F	2.3	Yes	7	33 W 2 D	FGR	22	33.2	15.9	0.83	0.52	35.2	15.8	0.89	0.55	33.4	14.7	0.91	0.56	38.7	17	0.91	0.56	C	Yes	A
13	F	0.9	Yes	7	32 W	FGR	4	32.5	9.8	1.2	0.7	33.4	9	1.28	0.73	38.2	9.9	1.31	0.74	34.4	7.9	1.38	0.77	U	No	A
14	F	2.1	Yes	10	40 W 4 D	FGR	14	33.2	12.3	1.05	0.63	34.2	11.3	1.14	0.67	31.1	10	1.16	0.68	38.2	11.8	1.19	0.69	U	No	A
15	M	1.8	Yes	9	35 W 3 D	FGR	12	35.9	12.2	1.12	0.66	36.9	11.4	1.19	0.69	35.2	10.9	1.18	0.69	41	12.7	1.18	0.69	U	No	A
16	M	2.2	Yes	7	33 W	FGR	18	33.2	18.3	0.71	0.45	33.2	16.3	0.81	0.51	34.5	17.3	0.79	0.5	41.8	18.8	0.89	0.55	GMH	Yes	A
17	M	1.8	Yes	8	35 W 5 D	FGR	15	30.5	10.1	1.13	0.67	30.5	9.8	1.16	0.68	29.4	9.1	1.18	0.69	42.6	13.6	1.16	0.68	U	No	A
18	M	2.1	Yes	9	37 W 5 D	FGR	12	41.4	14.9	1.07	0.64	37.7	12.4	1.14	0.67	42.5	14	1.14	0.67	43.4	13.5	1.18	0.69	U	No	A
19	M	1.1	Yes	8	34 W	FGR	28	32.1	6.1	1.49	0.81	36	6.1	1.55	0.83	39.6	7.1	1.52	0.82	42.1	7.2	1.55	0.83	PVL	Yes	A
20	F	1.9	Yes	7	38 W 4 D	FGR	10	27.2	12	0.91	0.56	26.2	11.8	0.89	0.55	28.8	12.4	0.93	0.57	45	18	0.99	0.6	C	Yes	A
21	F	1.1	Yes	7	34 W 3 D	FGR	4	28.8	7.8	1.28	0.73	31.2	7.8	1.33	0.75	33.2	8.3	1.33	0.75	45.7	11.9	1.3	0.74	U	No	A
22	F	1.8	Yes	10	35 W 4 D	FGR	6	29.3	7.9	1.28	0.73	29.3	8.2	1.26	0.72	32.5	8.8	1.28	0.73	46.5	12.6	1.28	0.73	U	No	A
23	F	1.8	Yes	9	37W 5 D	FGR	9	42.8	8.1	1.49	0.81	42.8	8.6	1.46	0.8	41.5	7.9	1.49	0.81	47.3	9	1.49	0.81	U	No	A
24	M	1.2	Yes	10	35 W	FGR	6	37.3	16.4	0.91	0.56	37.3	16	0.93	0.57	45.2	19	0.95	0.58	48.1	19.2	0.99	0.6	U	No	A
25	M	1.4	Yes	8	38 W	FGR	11	32.5	9.4	1.23	0.71	36.4	10.9	1.21	0.7	27.4	8.2	1.21	0.7	48.9	14.2	1.23	0.71	U	No	A
26	M	1.4	Yes	7	32 W 5 D	FGR	21	38.2	20.6	0.73	0.46	39.2	20.4	0.76	0.48	48.2	24.6	0.78	0.49	45.7	22.9	0.79	0.5	GMH	Yes	A
27	M	2.2	Yes	8	39W 4 D	FGR	6	32.2	9	1.26	0.72	34.2	9.2	1.28	0.73	43.2	11.7	1.28	0.73	50.5	13.1	1.31	0.74	U	No	A
28	F	1.3	Yes	7	34 W	FGR	3	34.1	10.9	1.16	0.68	34.1	11.3	1.13	0.67	35.5	11.4	1.16	0.68	51.3	14.9	1.23	0.71	U	No	A
29	F	2.3	Yes	7	39 W 1 D	FGR	7	26.2	11	0.95	0.58	26.2	10	1.03	0.62	27.6	9.9	1.07	0.64	42	14.3	1.11	0.66	U	No	A
30	M	1.4	Yes	8	35 W	FGR	8	24.5	6.6	1.28	0.73	24.5	6.4	1.3	0.74	25.5	6.4	1.33	0.75	52.8	12.7	1.35	0.76	U	No	A
31	M	1.3	Yes	9	37 W 4 D	FGR	14	37.1	11.1	1.21	0.7	37.1	11.1	1.21	0.7	38.1	11	1.23	0.71	53.6	12.3	1.38	0.77	C	Yes	A
32	M	1.4	Yes	7	34 W 4 D	FGR	3	27.4	5.5	1.46	0.8	29.2	5.3	1.52	0.82	31.2	5.6	1.52	0.82	30.4	6.1	1.46	0.8	PVL	Yes	A
33	M	1.8	Yes	8	37 W 4 D	FGR	7	33.6	10.1	1.21	0.7	33.6	9.4	1.26	0.72	37.5	10.1	1.28	0.73	55.2	14.4	1.3	0.74	U	No	A
34	F	1.5	Yes	9	36 W 2 D	FGR	10	28.6	10.9	1.03	0.62	31.2	10.9	1.09	0.65	35	11.9	1.12	0.66	47.4	16.1	1.12	0.66	U	No	A
35	F	1	Yes	7	36 W 1 D	FGR	7	34.6	10.7	1.19	0.69	34.6	9.7	1.25	0.72	32	8.6	1.28	0.73	56.8	15.9	1.26	0.72	U	No	A
36	F	2.2	Yes	10	39 W 4 D	FGR	5	31.9	8	1.33	0.75	33.4	8.4	1.33	0.75	35.4	9.2	1.3	0.74	55.6	13.9	1.33	0.75	C	Yes	A
37	M	1.8	Yes	9	35 W 3 D	FGR	9	35.6	16	0.89	0.55	37.5	16.5	0.91	0.56	42.5	18.7	0.91	0.56	38.3	15.7	0.97	0.59	U	No	A
38	M	1.2	Yes	9	32 W 5 D	FGR	25	28.8	14.4	0.8	0.5	28.8	13.8	0.83	0.52	28.2	13.3	0.85	0.53	40.1	18.4	0.87	0.54	C	Yes	A
39	M	1.8	Yes	8	35 W 5 D	FGR	5	34.9	8.7	1.33	0.75	34.9	7.3	1.44	0.79	31.2	6.2	1.47	0.8	45.9	9.2	1.46	0.8	U	No	A
40	M	2.1	Yes	8	37 W 5 D	FGR	10	28.4	6.8	1.36	0.76	28.4	6.5	1.39	0.77	29.2	6.7	1.38	0.77	49.1	10.3	1.44	0.79	U	No	A
41	M	1.2	Yes	7	34 W	FGR	12	36.5	12.4	1.12	0.66	37.5	12.4	1.14	0.67	35.2	10.9	1.18	0.69	52.5	15.8	1.2	0.7	C	Yes	A
42	F	1.9	Yes	7	38 W 4 D	FGR	4	32.2	7.7	1.36	0.76	34.2	7.5	1.41	0.78	33.5	7.7	1.38	0.77	38.4	8.4	1.41	0.78	U	No	A
43	F	1.2	Yes	7	34 W 3 D	FGR	8	27.4	8.2	1.21	0.7	27.4	7.9	1.23	0.71	29.1	8.1	1.26	0.72	33.6	9.1	1.28	0.73	U	No	A
44	F	1.8	Yes	9	35 W 4 D	FGR	7	24.6	6.2	1.32	0.75	25.6	6.4	1.33	0.75	26.5	6.4	1.35	0.76	35.4	8.1	1.39	0.77	U	No	A
45	F	2.1	Yes	9	38 W 4 D	FGR	9	28.1	8.4	1.21	0.7	29.1	8.4	1.23	0.71	32.8	9.2	1.25	0.72	38.5	10	1.31	0.74	U	No	A
46	M	1.5	Yes	7	34 W 3 D	FGR	5	27.4	5.5	1.46	0.8	27.4	5.2	1.49	0.81	34.2	6.8	1.47	0.8	40.1	8	1.46	0.8	U	No	A
47	F	1.1	Yes	8	35 W 4 D	FGR	19	31.8	15.6	0.81	0.51	32.4	15.6	0.83	0.52	44	19.4	0.91	0.56	46.2	19.9	0.93	0.57	C	Yes	A
48	F	1.6	Yes	9	37W 5 D	FGR	7	35.2	12	1.11	0.66	36.8	12.9	1.09	0.65	41.2	12.8	1.18	0.69	44.5	12.9	1.23	0.71	U	No	A

S. No.	BABY GENDER	BABY WEIGHT (KG)	LBW	5 MIN APGAR SCORE	POG	AGA / FGR	NICU STAY	PSV-1 D	EDV-1 D	PI-1 D	RI-1 D	PSV-3 D	EDV-3 D	PI-3 D	RI-3 D	PSV-7 D	EDV-7 D	PI-7 D	RI-7 D	PSV-1 M	EDV-1 M	PI-1 M	RI-1 M	EVENTS	NEUROLOGIC AL OUTCOME	RO-RI
49	M	2.6	No	9	37 W 1 D	AGA	Nil	31.1	7.8	1.2	0.75	35.2	8.4	1.23	0.76	37	9.6	1.23	0.74	40.9	10.2	1.19	0.75	U	No	A
50	F	2.1	Yes	9	35 W 4 D	AGA	Nil	32.9	12.2	1.3	0.63	34.1	13	1.33	0.62	35.2	12.7	1.31	0.64	33.3	11.7	1.35	0.65	U	No	A
51	M	2.8	No	10	38 W 2 D	AGA	Nil	45.6	16.4	1.16	0.64	46.6	16.3	1.16	0.65	48	16.3	1.19	0.66	50.2	18.1	1.23	0.64	U	No	A
52	M	2.5	No	8	36 W	AGA	Nil	41.5	19.9	0.82	0.52	45.2	21.7	0.85	0.52	49.1	22.6	0.83	0.54	51.6	23.2	0.87	0.55	U	No	A
53	M	3	No	7	39 W 1 D	AGA	Nil	33.2	10.6	1.18	0.68	35.2	9.9	1.12	0.72	37.5	11.3	1.14	0.7	39	11.3	1.19	0.71	U	No	A
54	M	1.9	Yes	8	34 W 3 D	AGA	Nil	24.1	5.5	1.33	0.77	26.5	5.8	1.36	0.78	30.2	6.9	1.31	0.77	29.3	6.2	1.33	0.79	U	No	A
55	F	2.9	No	8	39 W 3 D	AGA	Nil	39.3	15.3	1.05	0.61	41.2	17.3	1.03	0.58	43.4	17.4	1.07	0.6	46.5	18.6	1.09	0.6	U	No	A
56	F	2.6	No	10	35 W	AGA	Nil	36.5	10.6	1.07	0.71	35.1	9.8	1.09	0.72	35.6	9.3	1.12	0.74	35.9	8.6	1.07	0.76	U	No	A
57	M	2.8	No	8	37 W 7 D	AGA	Nil	42.2	16	0.83	0.62	42.2	13.1	0.83	0.69	41.1	14	0.87	0.66	40.9	13.5	0.89	0.67	U	No	A
58	F	2.6	No	9	34 W 3 D	AGA	Nil	35.2	12	1.16	0.66	37.4	12.3	1.25	0.67	38.9	12.8	1.2	0.67	42.2	13.1	1.23	0.69	U	No	A
59	M	2.6	No	9	37 W 1 D	AGA	Nil	33.2	15.9	1.39	0.52	32.5	15.6	1.41	0.52	34.7	16.3	1.39	0.53	31.6	14.2	1.43	0.55	U	No	A
60	M	2.4	Yes	8	33 W 1 D	AGA	Nil	29.4	10	1.01	0.66	30.5	10.7	0.95	0.65	33.1	11.6	0.99	0.65	35.5	11.4	0.99	0.68	C	Yes	A
61	F	2.3	Yes	9	32 W	AGA	Nil	38.7	12.4	1.23	0.68	38.7	11.6	1.26	0.7	42.5	13.2	1.3	0.69	39	12.1	1.36	0.69	U	No	A
62	M	2.9	No	7	40 W 6 D	AGA	Nil	40.1	9.6	1.03	0.76	39	9.8	1.18	0.75	39.6	8.7	1.11	0.78	44.7	7.6	1.14	0.83	U	No	A
63	F	2.6	No	10	35 W	AGA	Nil	34.2	14.4	1.11	0.58	34.2	13.7	1.14	0.6	36.8	15.1	1.14	0.59	34.3	13.7	1.18	0.6	U	No	A
64	M	1.6	Yes	8	33 W 1 D	AGA	Nil	28.8	8.6	0.83	0.7	31.2	8.7	0.83	0.72	34.2	9.2	0.85	0.73	36.9	9.6	0.89	0.74	U	No	A
65	M	2.4	Yes	8	35 W 2 D	AGA	Nil	32.5	9.8	1.11	0.7	35.5	10.3	1.09	0.71	37.1	10.4	1.09	0.72	40.8	11	1.16	0.73	U	No	A
66	F	2.7	No	7	37 W 2 D	AGA	Nil	26.5	5.3	1.16	0.8	27.4	5.8	1.21	0.79	32.4	6.2	1.18	0.81	29.8	5.7	1.18	0.81	U	No	A
67	M	2.4	Yes	9	34 W 2 D	AGA	Nil	31.3	10	1.36	0.68	33.5	10.7	1.33	0.68	34.4	11	1.41	0.68	32.4	13	1.55	0.6	U	No	A
68	M	2.9	No	10	38 W 6 D	AGA	Nil	42.8	12	0.94	0.72	37.3	10.4	0.99	0.72	45.2	12.7	0.97	0.72	48.2	14	0.99	0.71	U	No	A
69	F	2	Yes	10	34 W	AGA	Nil	28.2	11.8	1.21	0.58	30.2	12.1	1.26	0.6	28.2	7.6	1.28	0.73	43.4	21.7	1.3	0.5	U	No	A
70	F	2.4	Yes	10	35 W	AGA	Nil	39.2	9.8	1.2	0.75	39.2	11.1	1.23	0.72	43.2	9.9	1.25	0.77	41.4	10.8	1.28	0.74	U	No	A
71	M	2.6	No	8	37 W 3 D	AGA	Nil	34.1	7.2	1.46	0.79	35	8.1	1.43	0.77	36.5	7.7	1.49	0.79	40.9	11.9	1.49	0.71	U	No	A
72	F	2.4	Yes	9	35 W	AGA	Nil	44.2	14.6	1.16	0.67	43.9	16.7	1.16	0.62	47.6	15.7	1.16	0.67	51.1	17.4	0.98	0.66	U	No	A
73	M	2.9	No	7	38 W 4 D	AGA	Nil	26.5	8.2	1.25	0.69	28.5	10	1.26	0.65	31.5	9.8	1.25	0.69	34.7	8.3	1.23	0.76	U	No	A
74	M	2.6	No	10	36 W	AGA	Nil	36.1	8.7	0.95	0.76	37.1	8.5	0.99	0.77	38.1	9.1	1.28	0.76	43.3	10	0.8	0.77	U	No	A
75	M	3	No	8	39 W	AGA	Nil	41.4	13.2	1.33	0.68	48.6	15.6	1.25	0.68	49.2	15.7	1.38	0.68	53.3	10.7	1.3	0.8	U	No	A
76	M	2.5	No	10	34 W 3 D	AGA	Nil	31.6	7.6	1.43	0.76	30.6	7.7	1.38	0.75	27.5	6.6	1.43	0.76	29.9	7.8	1.23	0.74	U	No	A
77	F	3	No	8	39 W	AGA	Nil	28.6	10	1.14	0.65	31.2	8.7	1.03	0.72	35	10.5	1.14	0.7	37.6	12.8	1.11	0.66	U	No	A
78	F	2	Yes	9	35 W 1 D	AGA	Nil	26.6	8.8	1.18	0.67	30.6	9.5	1.09	0.69	32	10.6	1.18	0.67	34.4	9.6	1.36	0.72	U	No	A
79	M	2.6	No	10	37 W 5 D	AGA	Nil	31.9	8	1.35	0.75	33.4	7.3	1.38	0.78	35.4	8.9	1.36	0.75	38.6	9.7	1.38	0.75	U	No	A
80	F	2.6	No	7	34 W 3 D	AGA	Nil	35.6	11.7	1.16	0.67	37.5	10.5	1.16	0.72	42.5	11.9	1.16	0.72	38.8	12	1.46	0.69	U	No	A
81	M	2.7	No	7	37 W 4 D	AGA	Nil	28.8	11.5	1.35	0.6	28.8	11.8	1.33	0.59	28.2	11.6	1.36	0.59	31.8	14.6	1.3	0.54	U	No	A
82	M	2.3	Yes	8	36 W 2 D	AGA	Nil	34.9	10.5	1.09	0.7	34.9	10.1	1.26	0.71	37.2	10.4	1.21	0.72	40.1	8	1.11	0.8	U	No	A
83	F	1.8	Yes	7	32 W	AGA	Nil	26.4	6.6	1.14	0.75	28.4	6.8	1.18	0.76	29.2	7.3	1.13	0.75	32.2	6.8	1.26	0.79	U	No	A
84	M	2.3	Yes	10	39 W 2 D	AGA	Nil	37.5	12.4	1.33	0.67	37.5	11.3	1.41	0.7	35.2	10.9	1.33	0.69	44.8	13.4	1.33	0.7	U	No	A
85	F	3.1	No	9	35 W 6 D	AGA	Nil	33.2	8.3	1.14	0.75	35.2	8.4	1.26	0.76	33.5	8	1.26	0.76	39.3	8.6	1.19	0.78	U	No	A
86	M	1.8	Yes	9	32 W 2D	AGA	Nil	32.4	11	0.99	0.66	37.4	10.8	0.97	0.71	39.1	9.8	0.96	0.75	43.4	11.7	0.87	0.73	U	No	A
87	M	2.9	No	10	35 W 2 D	AGA	Nil	25.6	7.7	1.2	0.7	25.6	7.7	1.23	0.7	26.5	7.2	1.26	0.73	42.9	9.9	1.46	0.77	U	No	A
88	F	2.4	Yes	8	37 W	AGA	Nil	28.1	9.6	1.33	0.66	28.1	9	1.36	0.68	31.8	9.9	1.33	0.69	49.2	12.8	1.43	0.74	U	No	A
89	M	2.9	No	10	34 W 3 D	AGA	Nil	27.4	9.6	1.14	0.65	30.4	10.3	1.2	0.66	34.2	12	1.18	0.65	36.8	7	1.21	0.81	U	No	A
90	M	2.4	Yes	10	34 W 3 D	AGA	Nil	31.8	12.1	1.33	0.62	32.4	12.6	1.36	0.61	35.5	14.2	1.36	0.6	32.6	13.7	1.41	0.58	U	No	A
91	F	3.2	No	9	38 W 5 D	AGA	Nil	37.6	10.5	1.12	0.72	39.6	11.5	1.23	0.71	44.2	12.4	1.33	0.72	46.3	13.4	1.28	0.71	U	No	A
92	F	2.5	No	7	35 W 1 D	AGA	Nil	33.77	10.86	1.21	0.68	25.6	6.9	1.21	0.73	37.25	11.5	1.28	0.69	40.31	12.12	1.38	0.7	U	No	A
93	F	3	No	10	38 W 4 D	AGA	Nil	28.1	9	1.11	0.68	29.9	10.8	1.16	0.64	31.8	11.4	1.18	0.64	49.2	10.8	1.3	0.78	U	No	A
94	M	2.2	Yes	8	34 W 3 D	AGA	Nil	27.4	9.6	1.09	0.65	25.4	8.6	1.12	0.66	30.2	10.6	1.09	0.65	38.8	15.5	1.49	0.6	C	Yes	A
95	F	2.6	No	9	35 W 4 D	AGA	Nil	32.8	7.3	1.03	0.77	30.4	8.5	1.01	0.72	44	12.3	0.99	0.72	32.6	10.1	0.95	0.69	U	No	A
96	F	2.4	Yes	10	37W 5 D	AGA	Nil	37.6	10.5	1.26	0.72	39.6	11.5	1.23	0.71	46.2	12.9	1.25	0.72	46.3	13	1.23	0.72	U	No	A