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Original Article PEDIATRICS

The impact of mode of delivery on intestinal wall microvascularity in healthy newborns is studied using Superb Microvascular Imaging Doppler technique

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ABSTRACT

OBJECTIVE: This study aimed to investigate whether the mode of delivery influences intestinal microperfusion in healthy term neonates and to evaluate the utility of Superb Microvascular Imaging (SMI) in assessing neonatal intestinal microcirculation.

METHODS: A total of 45 healthy term neonates born between 38 and 40 weeks of gestation were prospectively enrolled. Twenty-six infants were delivered by cesarean section (C/S) and 19 by normal spontaneous vaginal delivery (NSVD). Intestinal microperfusion was assessed within the first 48 hours of life using monochrome SMI (mSMI) and color SMI (cSMI). Conventional Doppler techniques, including Color Doppler Imaging (CDI), Power Doppler Imaging (PDI), and Advanced Dynamic Flow (ADF), were also performed. Intestinal vascularity was semi-quantitatively scored and compared between groups.

RESULTS: No significant difference in intestinal microperfusion was observed between neonates delivered by C/S and NSVD using either mSMI (p=0.507) or cSMI (p=0.720). Similarly, no significant differences were detected using CDI, PDI, or ADF. However, mSMI demonstrated significantly higher detection of intestinal vascularity compared to cSMI (p<0.0001) and conventional Doppler modalities, which failed to detect vascular signals in a substantial proportion of cases.

CONCLUSION: Mode of delivery does not appear to significantly affect early intestinal microperfusion in healthy term neonates. Superb Microvascular Imaging, particularly mSMI, provides a sensitive and non-invasive method for visualizing neonatal intestinal microcirculation. These findings support the potential role of SMI in establishing reference perfusion patterns and in the early detection of gastrointestinal perfusion abnormalities in neonates.

Keywords: Cesarean section; delivery mode; microperfusion; normal spontaneous vaginal delivery; Superb Microvascular Imaging.

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Many important adjustments occur in newborns during the shift from the fetal period to neonatal life. The most urgent processes in the neonatal transition are the initiation of air breathing and the remodeling of the circulatory system to a postnatal circulation [1–3]. Hemodynamic postnatal adaptation may be different in infants born by cesarean section (C/S) and those born through normal spontaneous vaginal delivery (NSVD). The concentrations of umbilical artery adenosine and catecholamine have been found to differ significantly between NSVD and C/S [4], suggesting that early neonatal cardiovascular patterns may differ according to the delivery mode [5]. However, studies conducted on healthy term infants are limited, and it has been shown

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that hemodynamic adaptation is independent of the mode of delivery, with no significant difference found [6, 7]. Nevertheless, there is insufficient data on this subject.

The intestinal circulation alters considerably throughout the shift from fetal to newborn life. These hemodynamic changes affect organ perfusion and affect functions such as gastrointestinal absorption, secretion and movement [8]. Radiologic methods which demonstrate perfusion of the gastrointestinal system include Conventional Doppler imaging, CEUS (contrast-enhanced ultrasonography), and SMI (Superb Microvascular Imaging) [9–12].

Conventional Doppler imaging including Color Doppler Imaging (CDI), Power Doppler Imaging (PDI), and Advanced Dynamic Flow (ADF) do not optimally show slow or small flows [13]; therefore, it cannot be used for the clinical evaluation of the microvascular system. CEUS involves the intravenous administration of contrast agents composed of gas microbubbles and evaluates vascularity more effectively. The need for intravenous contrast injection and the time-consuming procedure may explain why CEUS is not used in clinical practice routinely [14].

SMI is defined as the noninvasive method that best demonstrates microvascular perfusion [15]. SMI uses color Doppler technology and allows the imaging of low-flow small vessels in high resolution, with minimal artifacts at high frame rates. Imaging of low-flow signals with SMI is of great value for early diagnosis and treatment of cancers, tumors, rheumatologic diseases, and many other medical diseases. SMI analyzes motion and uses a new algorithm to identify correct blood flow by eliminating tissue motion. It has two modes, namely monochrome SMI (mSMI) and color SMI (cSMI). Monochrome mode focuses only on vascularization by eliminating background information whereas color mode simultaneously demonstrates B-mode and color information, increasing sensitivity. SMI is an excellent application for visualizing blood flow in surface lesions and has significant potential in recognizing low-grade inflammation, which was not possible before. With this technology, safe diagnoses can be made and patient management and clinical effects can be monitored [16].

It is not stated in the literature that gastrointestinal perfusion in newborns transitioning from fetal life to neonatal life may vary depending on the type of birth. In our study, we aimed to evaluate the effect of mode of delivery on intestinal microperfusion in newborns using SMI technique.

Highlight key points

- Neonatal intestinal microperfusion was non-invasively assessed using Superb Microvascular Imaging (SMI).
- Early intestinal microperfusion did not differ according to mode of delivery.
- SMI shows promise for evaluating neonatal intestinal microcirculation in healthy term infants.

MATERIALS AND METHODS

This study was conducted over the course of one year with a total of 45 infants, 26 of whom were born by C/S and 19 by NSVD, who presented to the Obstetrics and Gynecology Service at Istanbul Medeniyet University, Goztepe Training and Research Hospital, affiliated with the Ministry of Health. Informed consent was obtained from all participants. The study was designed in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Istanbul Medeniyet University Goztepe Training and Research Hospital Clinical Research (Decision number 2015/0135).

Patients

Clinical examination and routine tests of each newborn included in the study were performed. The infants were divided into two groups according to the delivery mode: those who were born by NSVD and those who were born by C/S.

Newborns included in the study were those born between the 38th and 40th weeks of gestation. Ultrasonography (USG) was evaluated in these babies within the first 48 hours postnatally.

Exclusion criteria included infants who required admission to the neonatal intensive care unit, preterm infants, and those with signs of perinatal asphyxia (as indicated by abnormal cord blood gases: pH<7.20, PCO_2>55 mmHg, HCO_3<24 mEq/L). Additionally, infants with multiple congenital anomalies or cyanotic congenital heart disease were excluded from the study.

Demographic characteristics and delivery details of the included newborns were recorded. These included maternal age, gestational age, and pregnancy history (number of pregnancies, live births, miscarriages, and stillbirths). Birth-related details such as birth weight, gender, Apgar scores at 1 and 5 minutes, mode of delivery (C/S or NSVD), and the time and date of birth were also documented. During postnatal examinations, the overall condition of the newborns, including color,

Table 1. Comparison of four quadrants with mSMI

	mSMI RUQ n=42 %	mSMI RLQ n=42 %	mSMI LUQ n=42 %	mSMI LLQ n=42 %	
Stage 0	21.43	2.38	11.90	11.90	RUQ/RLQ
Stage 1	7.14	7.14	2.38	4.76	κ_w:0.205 p=0.048
Stage 2	11.90	16.67	9.52	14.29	LUQ / LLQ
Stage 3	23.81	16.67	16.67	16.67	κ_w:0.284 p=0.002
Stage 4	35.71	57.14	59.52	52.38	

mSMI: Monochrome Superb Microvascular Imaging; LLQ: Left lower quadrant; LUQ: Left upper quadrant; RLQ: Right lower quadrant; RUQ: Right upper quadrant; K_w: Kiloohm.

Table 2. Comparison of four quadrants with cSMI

	cSMI RUQ n=42 %	cSMI RLQ n=42 %	cSMI LUQ n=41 %	cSMI LLQ n=41 %	
Stage 0	26.19	9.52	14.63	21.95	RUQ / RLQ
Stage 1	7.14	16.67	4.88	4.88	κ_w:0.208 p=0.047
Stage 2	30.95	16.67	17.07	21.95	LUQ / LLQ
Stage 3	11.90	21.43	19.51	19.51	κ_w:0.287 p=0.001
Stage 4	23.81	35.71	43.90	31.71	

cSMI: Color Superb Microvascular Imaging; LLQ: Left lower quadrant; LUQ: Left upper quadrant; RLQ: Right lower quadrant; RUQ: Right upper quadrant; K_w: Kiloohm.

activity, respiratory rate, presence of grunting or bruising, oxygen saturation (SaO_2), and cardiac auscultation findings were evaluated. After the infants were returned to their mothers, a repeat physical examination was performed between 6 and 24 hours of life. Newborns with pathological conditions or those requiring postnatal oxygen support were excluded from the study. In addition, detailed prenatal history was collected from mothers.

Ultrasonography Method and Evaluation

The examinations were performed right after feeding in the supine position in an obscure and quiet room to evaluate the newborns calmly. All examinations were performed by the same radiologist using a heated gel and a high-resolution multifrequency linear probe (7.2-14 MHz) (Aplio 500; Toshiba Medical Systems). After selecting the best visible intestinal loop in four quadrants of the abdomen and getting gray-scale images in at least two planes, the intestinal blood flow was evaluated using monochrome and color Superb Microvascular Imaging (SMI) techniques, respectively, and 5-10-second-short clips were recorded. Pulse repetition frequency and Doppler gain settings were adjusted to demonstrate the most sensitive blood supply without artifacts. Frame rate values were 55-60 pulse/s in SMI. All images were saved in discs in DICOM format. Then CDI, PDI, and ADF assessments were performed on the visible intestinal loop for each patient.

Evaluation and Measurements

Gray-scale and Doppler images were co-evaluated by a pediatric radiologist and the final-year radiology assistant who performed the examinations, on high-resolution Picture Archiving and Communication System (PACS) monitors, and consensus was reached. The evaluation was made for each case independently and blindly according to their clinical information.

Table 3. Comparison of hematological parameters according to delivery mode

	NSVD n=19	C/S n=26	p
Leukocyte	15.84±5.51	14.08±5.21	0.313
Hemoglobin	16.08±1.54	15.54±2.68	0.456
Hematocrit	46±5.66	43.48±8.16	0.277
MCV	103.1±4.78	103.44±5	0.831
PLT	238.06±50.85	235.95±63.53	0.911
MPV	6.62±0.75	6.41±0.5	0.312
Urea	19.6±6.32	21.79±8.55	0.414
Creatine	0.62±0.1	0.68±0.1	0.084
Na	141.47±1.85	141.42±3.37	0.963
Ca	9.22±0.54	8.59±1.8	0.233
Magnesium	1.91±0.1	1.88±0.11	0.507
ALP	197.75±83.42	150.25±36.71	0.163
ALT	19.87±8.79	16.84±6.88	0.268
AST	65.19±19.86	62.88±23.52	0.768
Uric acid	4.42±1.51	4.65±1.53	0.739

ALP: Alkaline phosphatase; ALT: Alanine aminotransferase; AST: Aspartate aminotransferase; C/S: Cesarean section; MCV: Mean corpuscular volume; MPV: Mean platelet volume; NSVD: Normal spontaneous vaginal delivery; PLT: Platelet count.

Table 4. Evaluation of intestinal microperfusion with mSMI-cSMI according to delivery method

	NSVD n=19 (%)	C/S n=26 (%)	p
mSMI RUQ			0.507
Stage 1	5.56	8.33	
Stage 2	11.11	4.17	
Stage 3	0.00	8.33	
Stage 4	83.33	79.17	
cSMI RUQ			0.720
Stage 1	5.56	12.50	
Stage 2	5.56	12.50	
Stage 3	27.78	20.83	
Stage 4	61.11	54.17	
ADF RUQ			0.935
Stage 0	55.56	50.00	
Stage 1	11.11	16.67	
Stage 2	27.78	25.00	
Stage 3	5.56	8.33	
CDI RUQ			0.054
Stage 0	88.89	50.00	
Stage 1	11.11	29.17	
Stage 2	0.00	16.67	
Stage 4	0.00	4.17	
Power RUQ			0.975
Stage 0	33.33	37.50	
Stage 1	11.11	12.50	
Stage 2	38.89	29.17	
Stage 3	11.11	12.50	
Stage 4	5.56	8.33	

ADF: Advanced dynamic flow; C/S: Cesarean section; CDI: Color Doppler imaging; CSMI: Color Superb Microvascular Imaging; MSMI: Monochrome Superb Microvascular Imaging; NSVD: Normal spontaneous vaginal delivery; RUQ: Right upper quadrant.

The degree of intestinal blood flow in each quadrant was classified between 0-4. Stage 0: none or 1 color focus spot; Stage 1: 2-3 color focus spots; Stage 2: 3-5 color focus spots; Stage 3: linear color focus; Stage 4: Multiple linear color focus.

Statistical Analysis

In this study, statistical analyses were performed using the NCSS (Number Cruncher Statistical System) 2007 Statistical Software (Utah, USA) package program. In the evaluation of data, in addition to descriptive statistical methods (mean, standard deviation), one-way analysis of variance was used in the comparisons between multiple groups; the independent samples t-test was used in the comparison of paired groups; Chi-square test was used in the comparison of qualitative data; weighted Kappa test was used to test the compatibility of radiological measurements; Pearson correlation analysis was used in determining the correlations between the variables.

RESULTS

A total of 45 newborns, 26 of whom were born with C/S (Group 1) and 19 were born with NSVD (Group 2), who were born at gestational weeks of 38-40, and who had no antenatal and postnatal problems were included in the study. Three cases were excluded.

The infants' abdomens were divided into four quadrants and evaluated with mSMI and cSMI. There were differences in the four quadrants in both mSMI and cSMI (Table 1, 2). Consequently, the data from the four quadrants were averaged to provide a more reliable assessment.

Table 5. Comparison of mSMI and cSMI

mSMI RUQ	Stage 1 (%)		Stage 2 (%)		Stage 3 (%)		Stage 4 (%)		p
cSMI RUQ									**0.0001**
Stage 1	3	100.0	0	0.00	0	0.00	1	2.94	
Stage 2	0	0.00	0	0.00	2	100.0	2	5.88	
Stage 3	0	0.00	2	66.67	0	0.00	8	23.53	
Stage 4	0	0.00	1	33.33	0	0.00	23	67.65	
ADF RUQ									0.693
Stage 0	3	100.0	2	66.67	1	50.00	16	47.06	
Stage 1	0	0.00	0	0.00	1	50.00	5	14.71	
Stage 2	0	0.00	1	33.33	0	0.00	10	29.41	
Stage 3	0	0.00	0	0.00	0	0.00	3	8.82	
CDI RUQ									0.719
Stage 0	2	66.67	3	100.0	1	50.00	22	64.71	
Stage 1	1	33.33	0	0.00	0	0.00	8	23.53	
Stage 2	0	0.00	0	0.00	1	50.00	3	8.82	
Stage 4	0	0.00	0	0.00	0	0.00	1	2.94	
Power RUQ									0.058
Stage 0	3	100.0	1	33.33	1	50.00	10	29.41	
Stage 1	0	0.00	0	0.00	0	0.00	5	14.71	
Stage 2	0	0.00	0	0.00	0	0.00	14	41.18	
Stage 3	0	0.00	2	66.67	1	50.00	2	5.88	
Stage 4	0	0.00	0	0.00	0	0.00	3	8.82	

ADF: Advanced dynamic flow; CDI: Color Doppler imaging; cSMI: Color Superb Microvascular Imaging; mSMI: Monochrome Superb Microvascular Imaging; RUQ: Right upper quadrant.

To ensure that the study focused solely on the effect of delivery mode on gastrointestinal perfusion, potential confounding factors such as hematological parameters were controlled. Hematological parameters of both groups were found to be similar (Table 3), suggesting no significant differences in intravascular viscosity that could impact intestinal perfusion.

Intestinal microperfusion was assessed using mSMI and cSMI based on the delivery method. Statistical analysis revealed no significant difference in microperfusion between the two groups (C/S vs. NSVD) (p=0.507 for mSMI, p=0.720 for cSMI). Similarly, evaluations using CDI, PDI, and ADF showed no significant differences (Table 4).

When comparing the imaging techniques, mSMI detected significantly higher vascularity in the intestinal areas compared to cSMI (p=0.0001). Importantly, no patient exhibited a complete absence of vascularity. However, vascularity was not detected in 22 (52%) patients using ADF, 28 (66.6%) using CDI, and 15 (35.7%) using PDI (Table 5).

When the quadrants were assessed separately, the mSMI demonstrated a consistent pattern of high perfusion stages across all regions, particularly in the left upper quadrant (LUQ) and left lower quadrant (LLQ). There was significant statistical agreement between the parties (κw=0.284, p=0.002). In contrast, this consistency was less pronounced with the cSMI and was not observed in the ADF, CDI, or PDI assessments.

Furthermore, the right upper quadrant (RUQ)-specific analysis (Table 5) revealed a significant difference in perfusion staging between the mSMI and cSMI (p=0.0001). This suggests that the mSMI detects higher-grade vascular signals more reliably than the cSMI in the same anatomical region.

DISCUSSION

The early postnatal period is considered a critical period of hemodynamic adaptation, particularly affecting gastrointestinal perfusion. Adequate intestinal microcirculation is essential for nutrient absorption and intestinal barrier integrity, whereas impaired perfusion is thought to contribute to serious neonatal complications such as necrotizing enterocolitis. Despite its importance, non-invasive assessment of intestinal perfusion in neonates is limited in clinical practice [8]. In our study, which was planned with the need for an effective diagnostic method in this patient group, we found no significant difference in intestinal perfusion depending on mode of delivery, suggesting that early intestinal perfusion in healthy term infants may not be significantly affected by mode of delivery. According to the literature, this is one of the first studies to apply SMI to neonatal intestinal microvascularity and provides important information about the applicability of the method in this field by demonstrating how the SMI technique can be used to assess intestinal microcirculation in neonates.

In our study, we also analyzed multiple perinatal variables such as gestational age, birth weight, Apgar scores and gender, none of which showed a significant association with gut perfusion in the first 48 hours. However, it is worth noting that our cohort consisted only of healthy term newborns.

Another important aspect of our findings is the comparison between mSMI and cSMI modes. mSMI achieves significantly higher vascular signal, with the technical advantage of suppressing background and improving visualization of low-flow vessels. This may have clinical relevance, as mSMI provides clearer vascular delineation with minimal motion obstruction, suggesting that it may be a useful tool in neonatal intensive care settings for early detection of perfusion abnormalities, especially in at-risk infants. While mSMI successfully detected vascularity in all patients, conventional Doppler modalities failed to detect a vascular signal in a significant proportion of patients: 52% with ADF, 66.6% with CDI, and 35.7% with PDI. These results suggest that conventional Doppler methods may underestimate intestinal perfusion, particularly during the early neonatal period when blood flow is low and vessels are small.

Establishing reference values for intestinal microperfusion using SMI in healthy term neonates is another contribution of our study. Early identification of impaired intestinal perfusion in neonates at risk for gastrointestinal complications such as necrotizing enterocolitis, intestinal ischemia or sepsis may guide supportive interventions or monitoring strategies before clinical deterioration occurs [17, 18]. Therefore, integrating SMI into routine or targeted neonatal assessments may improve risk stratification and early diagnosis of intestinal microcirculatory disorders.

The most important limitations of our study are the small sample size and therefore the generalizability of our findings is limited. Although our study was designed as a pilot study, future studies with larger and more diverse populations are needed to confirm and extend these results. Second, we did not assess cardiovascular parameters, which may help clarify the relationship between systemic hemodynamics and gut perfusion. Inclusion of echocardiographic assessment in future studies may increase understanding of the physiological mechanisms involved in postpartum perfusion dynamics.

In conclusion, this study demonstrated that mode of delivery does not significantly affect early intestinal microperfusion in healthy term newborns. The use of SMI - especially monochrome mode (mSMI) - proved to be a sensitive, non-invasive method to visualize neonatal intestinal microvascular flow. These findings provide a basis for future research and suggest that SMI may be a promising tool for early detection of gastrointestinal perfusion abnormalities. Larger studies including echocardiographic measurements and at-risk neonatal populations are needed to better understand the clinical applications of this technique.

Ethics Committee Approval: The Istanbul Medeniyet University Goztepe Training and Research Hospital Clinical Research Ethics Committee granted approval for this study (date: 12.10.2015, number: 2015/0135).

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