

Feasibility of Continuous Multi-Site Skin Temperature Monitoring for Physiological Assessment of Suspected Necrotizing Enterocolitis in Preterm Infants: A Pilot Study

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Abstract

This pilot study aimed to evaluate the technical feasibility of continuous, non-invasive, multi-site skin temperature monitoring in preterm infants already clinically suspected of NEC, and to characterise preliminary temperature signal features during a standardised 20-minute monitoring epoch. Preterm infants clinically suspected of early-stage NEC were enrolled and underwent continuous physiological monitoring, including abdominal, hand, and foot skin temperature measurements. A total of 16 preterm infants were included in the analysis. The results showed that temperature variations across measurement sites were minimal and did not demonstrate clear differentiation among subjects during the monitoring period. These findings suggest that temperature-based monitoring alone may have limited sensitivity for early NEC detection, particularly in mild or early-stage cases. Importantly, this study demonstrates that continuous multi-site physiological monitoring is technically feasible in the neonatal intensive care setting. The findings highlight the need to integrate additional physiological parameters to enhance the sensitivity and reliability of future monitoring strategies. These preliminary results provide insights into the limitations of single-parameter monitoring and support the development of multi-modal, data-driven approaches for early NEC assessment in preterm infants.

Keywords

Necrotizing Enterocolitis, Preterm Infants, Non-Invasive Monitoring, Skin

1. Introduction

Necrotizing enterocolitis (NEC) is a critical gastrointestinal disease in preterm infants and remains a leading cause of morbidity and mortality in neonatal intensive care units [1]-[4]. Early identification is essential to prevent severe complications, yet diagnosis remains challenging due to nonspecific early symptoms [5] [6]. Previous studies have explored physiological indicators, including perfusion-related parameters and thermal regulation, to assess neonatal circulatory status and detect early abnormalities [7]-[10].

Several physiological monitoring strategies have been explored as adjuncts to clinical assessment for earlier NEC identification. Peripheral perfusion indices, heart rate variability, and near-infrared spectroscopy have shown promise individually, yet each captures only one dimension of the underlying pathophysiology [5]-[7] [9] [11]-[13]. Skin temperature at peripheral and central sites provides an accessible, non-contact correlate of circulatory redistribution: as splanchnic vasoconstriction occurs, abdominal-peripheral temperature gradients may widen in proportion to haemodynamic compromise [9] [10] [14]. However, whether such gradients are detectable with sufficient resolution during mild or suspected NEC, before overt clinical deterioration, has not been systematically evaluated. The present pilot study therefore addressed two specific objectives: to determine whether continuous, multi-site skin temperature recording is technically feasible in a NICU environment during a standardised 20-minute epoch, and to characterise the preliminary temperature signal features, including inter-site gradients and intra-individual variability in a cohort of preterm infants with clinically suspected NEC.

2. Methods

2.1. Study Design and Participants

This study was designed as a prospective observational pilot study conducted in a neonatal intensive care unit between July 2017 and July 2018. Preterm infants (gestational age < 37 weeks) who were clinically suspected of having early-stage necrotizing enterocolitis (NEC) by attending physicians were eligible for inclusion. Enrollment was consecutive: all eligible infants identified during the recruitment period were approached, and no eligible infant was excluded after meeting inclusion criteria. The enrolled sample of 16 infants was determined by the duration of the recruitment period and is intended to provide preliminary feasibility data rather than definitive estimates of diagnostic accuracy.

Exclusion criteria included severe congenital anomalies, congenital heart disease, severe infection, grade III or higher intraventricular hemorrhage, periventricular leukomalacia, requirement for surgical intervention, or end-of-life care status. Written informed consent was obtained from parents or legal guardians prior to partic-

ipation. The study protocol was approved by the Institutional Review Board of Taichung Veterans General Hospital (IRB Approval No.: SF17169B), and all procedures were conducted in accordance with the Declaration of Helsinki (**Table 1**).

Table 1. Basic characteristics of preterm infants (n = 16).

Variable	Min	Max	Mean \pm SD
Gestational age (weeks)	25	37	31.67 \pm 3.21
Birth weight (g)	530	2125	1153.13 \pm 329.24
APGAR score (1 minute)	1	7	4.27 \pm 2.09
APGAR score (5 minutes)	2	8	6.80 \pm 1.66

2.2. Experiment Architecture

The measurement workflow of the assessment system for detecting necrotizing enterocolitis (NEC) in preterm infants is as follows. When a preterm infant was clinically evaluated by a physician as having suspected NEC, four-point skin temperature sensors were immediately applied to predefined anatomical sites, including the central abdomen, dorsum of the hand, and dorsum of the foot. Temperature measurements were recorded over a fixed monitoring period of 20 minutes. The recording was initiated within 30 minutes of the attending physician's formal documentation of NEC suspicion, prior to the initiation of any new pharmacological treatment or surgical intervention, and at least 2 hours after the most recent enteral feed. A 20-minute epoch was chosen as a pragmatic compromise between capturing sufficient physiological data to characterise signal stability and minimising monitoring burden in a critical-care setting; this duration is consistent with recording windows used in comparable neonatal physiological feasibility studies.

The system architecture consisted of a custom-developed LABVIEW-based monitoring platform, which transmitted physiological data to a personal computer via RS-232 serial communication. All acquired data were continuously stored and archived on the computer for long-term recording. Subsequently, computational processing and data analysis were performed using programs developed within the LABVIEW environment, and the processed results were displayed in real time through a graphical user interface.

2.3. Physiological Monitoring System

A non-invasive monitoring system was developed to continuously record physiological parameters. Skin temperature was measured at multiple anatomical sites, including the central abdomen, dorsum of the hand, and dorsum of the foot, using a precision digital thermometer (TM-907A). Data were transmitted via RS-232 interface and recorded using a custom LabVIEW-based platform.

The system enabled real-time acquisition, visualization, and storage of physiological data. Measurements were collected over a standardized monitoring period and stored for subsequent analysis [15] [16] (**Figure 1**).

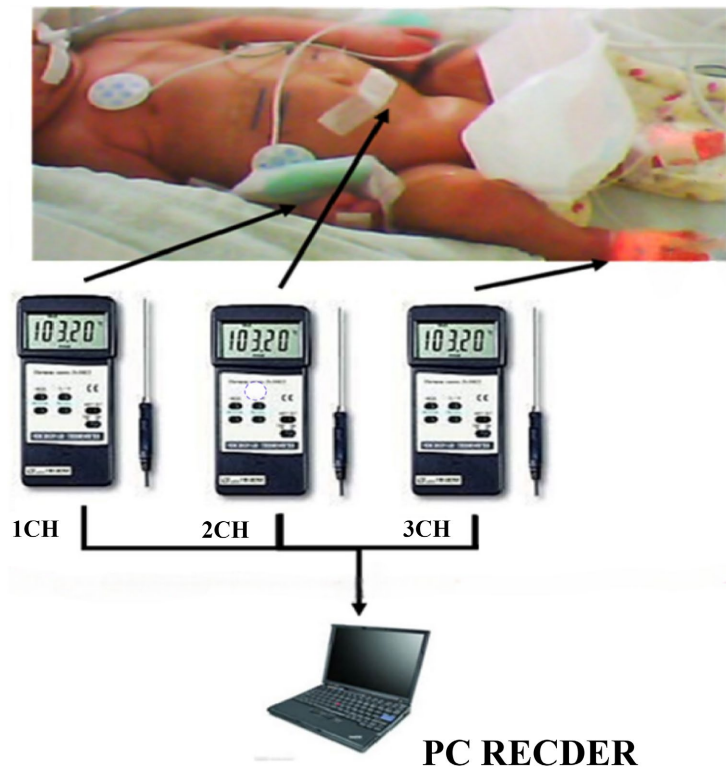


Figure 1. Premature infant monitoring system architecture diagram.

2.4. Measurement Equipment

A precision digital thermometer (TM-907A) with a type-K thermocouple probe was used for continuous skin temperature measurements at multiple anatomical sites. In the clinically relevant neonatal temperature range (34°C - 38°C), the device provides a resolution of 0.1°C and a measurement accuracy of $\pm (0.1\% + 0.2^{\circ}\text{C})$. Data were sampled at approximately 0.4-second intervals and transmitted continuously to the acquisition computer via RS-232 serial interface for real-time storage and subsequent analysis.

2.5. Software Development

A real-time monitoring system was developed using the LabVIEW graphical programming environment. Data transmission was achieved via RS-232 communication, enabling seamless integration of measurement hardware with software-based signal processing and data analysis modules. The LabVIEW platform provides built-in signal processing libraries and supports the development of customized graphical user interfaces, allowing clinicians to efficiently visualize and interpret physiological signals. The system offers high sensitivity for detecting subtle physiological changes, delivers accurate numerical measurements, supports high-resolution acquisition of physiological parameters and waveforms, and enables long-term continuous recording with data storage. In addition, real-time waveform displays and physiological parameter reports were updated at five-second intervals to enhance clinical monitoring and interpretation.

2.6. Data Collection

Physiological data, including multi-site skin temperature, were continuously recorded during bedside monitoring. Basic demographic and clinical information, including gestational age at enrolment, birth weight, Apgar scores, current clinical diagnoses, and ongoing medical and nursing interventions, were also collected for each participant using a standardised data collection form. The primary feasibility outcomes, defined a priori, were: 1) successful sensor placement at all three anatomical sites (abdomen, hand, and foot) without requiring repositioning; 2) the proportion of the 20-minute recording epoch yielding analyzable data (target: $\geq 80\%$ per participant); 3) frequency of signal loss events per session; and 4) occurrence of any skin-related adverse events (e.g., pressure marks, erythema, or skin breakdown) attributable to sensor contact. These feasibility metrics were assessed for every enrolled infant and are reported in the Results section.

2.7. Statistical Analysis

Descriptive statistics were used to summarize physiological parameters, including mean and standard deviation. Due to the exploratory nature of this pilot study and the limited sample size, formal inferential statistical testing was not emphasized. Trends in temperature variations across anatomical sites were visually and descriptively analyzed. Future studies with larger sample sizes are required to enable more robust statistical comparisons and model-based analysis.

3. Results

A total of 16 preterm infants clinically suspected of NEC were included in the analysis. According to the modified Bell's criteria, 9 infants were classified as stage I (suspected NEC), 6 as stage II (definite NEC), and 1 as stage III (advanced NEC). The single stage III case was identified retrospectively: the infant was enrolled at stage I presentation and progressed to stage III within 24 hours following the monitoring epoch, as confirmed by abdominal radiograph demonstrating intestinal perforation and clinical deterioration requiring surgical consultation.

Continuous physiological monitoring was successfully implemented in all 16 participants, demonstrating the feasibility of real-time, non-invasive data acquisition in a NICU setting. Regarding the pre-specified feasibility outcomes: sensor placement was achieved at all three anatomical sites in all 16 infants (100% placement success rate) without the need for repositioning after initial application. The mean proportion of analyzable recording time per participant was 97.3% (range: 94.1% - 100%), exceeding the 80% a priori threshold in every case. A total of three transient signal-loss events were recorded across the cohort (0.19 events per participant-session), each lasting fewer than 30 seconds and attributable to brief cable movement during routine nursing care. No skin-related adverse events, including pressure marks, erythema, or skin breakdown, were observed in any participant. All physiological data were successfully recorded and stored for analysis.

Analysis of temperature data examined four pre-specified signal features across

the 20-minute monitoring epoch for each subject (**Table 2**). Mean abdominal skin temperature across all subjects was $36.4^{\circ}\text{C} \pm 0.6^{\circ}\text{C}$ (range: $35.1^{\circ}\text{C} - 37.4^{\circ}\text{C}$), while mean hand and foot temperatures were $35.8^{\circ}\text{C} \pm 0.7^{\circ}\text{C}$ (range: $34.6^{\circ}\text{C} - 36.9^{\circ}\text{C}$) and $35.5^{\circ}\text{C} \pm 0.8^{\circ}\text{C}$ (range: $34.2^{\circ}\text{C} - 36.8^{\circ}\text{C}$), respectively. No statistically meaningful between-subject separation was observed across NEC stages for any measurement site. The mean abdomen-foot temperature differential (ΔT) across subjects was $0.9^{\circ}\text{C} \pm 0.6^{\circ}\text{C}$ (range: $0.1^{\circ}\text{C} - 2.1^{\circ}\text{C}$), and values did not demonstrate consistent elevation or directionality sufficient to distinguish stage I from stage II cases. In addition, intra-individual temperature variability remained low at all three measurement sites, with within-subject standard deviation values over the monitoring epoch ranging from 0.2°C to 0.4°C across subjects and sites (**Table 2**).

Table 2. Summary of pre-specified temperature signal features across all subjects ($n = 16$).

Signal Feature	Abdomen	Hand	Foot
Mean absolute temperature ($^{\circ}\text{C}$), mean \pm SD	36.4 ± 0.6	35.8 ± 0.7	35.5 ± 0.8
Range ($^{\circ}\text{C}$)	35.1 to 37.4	34.6 to 36.9	34.2 to 36.8
Within-subject SD over epoch ($^{\circ}\text{C}$), median (range)	0.3 (0.2 to 0.4)	0.3 (0.2 to 0.4)	0.3 (0.2 to 0.4)

Overall, the findings indicate that temperature-based measurements alone did not provide sufficient differentiation for identifying early-stage NEC in this cohort. The limited variability observed may be attributable to the relatively mild disease severity and small sample size (**Figures 2-4**).

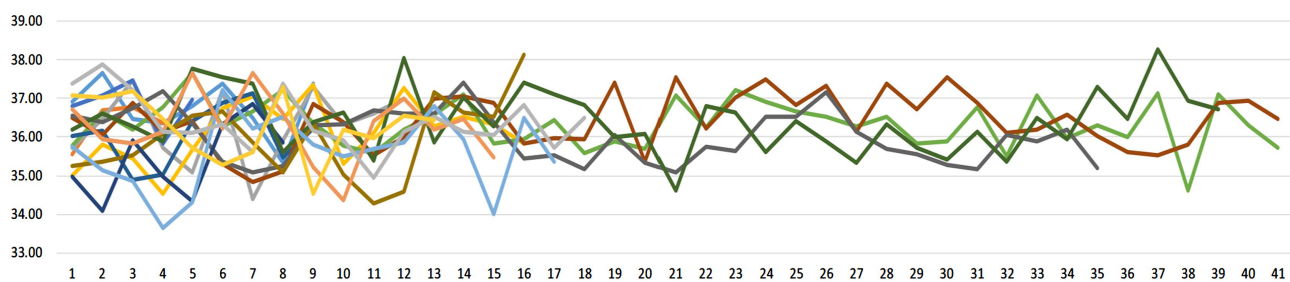


Figure 2. Measuring an infant's hand temperature.

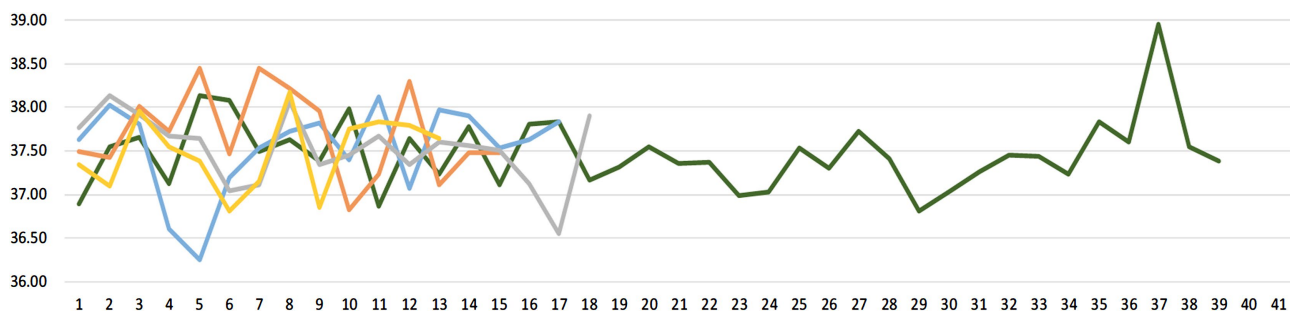


Figure 3. Measuring an infant's abdominal temperature.

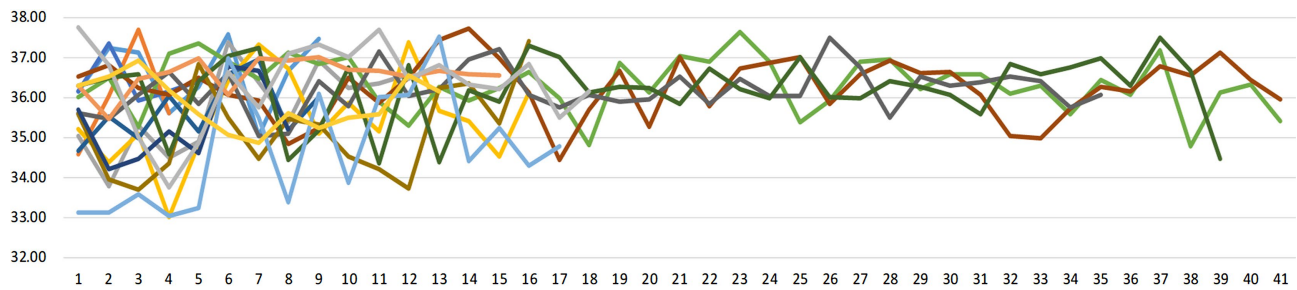


Figure 4. Measuring an infant's foot temperature.

4. Discussion

This pilot study evaluated the technical feasibility of continuous, multi-site skin temperature monitoring in preterm infants with clinically suspected NEC. An important limitation is that this study did not test prospective “early detection” in the strict sense: infants were enrolled only after clinical suspicion of NEC had already been raised, and monitoring was conducted over a single 20-minute epoch. The design therefore evaluates monitoring feasibility and signal characterisation, not the ability to detect NEC before clinical recognition. Contrary to initial expectations, temperature variations across measurement sites did not demonstrate clear or consistent patterns during the monitoring period.

One possible explanation is that most enrolled cases were classified as mild (stage I - II), where physiological changes may not yet be sufficiently pronounced to produce detectable temperature differences. Previous studies have shown that physiological signals in preterm infants can be highly variable and influenced by developmental status and environmental factors [17]-[20]. This finding suggests that temperature alone may lack sensitivity as an early biomarker for NEC.

Importantly, these results provide valuable insight into the limitations of single-parameter monitoring approaches. While temperature monitoring is non-invasive and clinically convenient, it may not adequately capture the complex physiological changes associated with early NEC. Prior studies have emphasized that peripheral perfusion and hemodynamic responses are multifactorial and may not be fully reflected by a single physiological parameter [21] [22].

This study demonstrates the feasibility of continuous, real-time physiological monitoring in a neonatal intensive care setting. The integration of additional physiological parameters may offer a more comprehensive and sensitive approach for early detection. Previous research has suggested that multi-modal monitoring, including cardiovascular and autonomic indicators, may improve the assessment of neonatal physiological stability [6] [13] [23] [24].

Future research should focus on multi-modal monitoring strategies and larger cohorts, particularly including more severe NEC cases, to better characterize physiological patterns and improve early diagnostic capabilities. In addition, clinical care strategies such as kangaroo care and supportive developmental interventions may further influence physiological regulation and should be considered in future investigations [25] [26]-[30].

5. Conclusions

This study evaluated the feasibility of multi-site skin temperature monitoring for the early assessment of necrotizing enterocolitis in preterm infants. The findings demonstrated that temperature variations alone did not provide sufficient discriminatory power for identifying early-stage NEC, particularly in cases with mild disease severity.

These results suggest that temperature-based monitoring, when used in isolation, may have limited clinical utility for early NEC detection. However, the study confirms the feasibility of continuous, non-invasive physiological monitoring in the neonatal intensive care environment.

Importantly, the findings highlight the need for integrating additional physiological parameters, such as multi-modal physiological data, to enhance sensitivity and diagnostic accuracy. Future studies with larger sample sizes and more severe NEC cases are warranted to further validate and refine this monitoring approach.

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Conflicts of Interest

There are no conflicts of interest to report.

References

- [1] Neu, J. and Walker, W.A. (2011) Necrotizing Enterocolitis. *New England Journal of Medicine*, **364**, 255-264. <https://doi.org/10.1056/nejmra1005408>
- [2] Niño, D.F., Sodhi, C.P. and Hackam, D.J. (2016) Necrotizing Enterocolitis: New Insights into Pathogenesis and Mechanisms. *Nature Reviews Gastroenterology & Hepatology*, **13**, 590-600. <https://doi.org/10.1038/nrgastro.2016.119>
- [3] Fitzgibbons, S.C., Ching, Y., Yu, D., Carpenter, J., Kenny, M., Weldon, C., *et al.* (2009) Mortality of Necrotizing Enterocolitis Expressed by Birth Weight Categories. *Journal of Pediatric Surgery*, **44**, 1072-1076. <https://doi.org/10.1016/j.jpedsurg.2009.02.013>
- [4] Gordon, P.V., Swanson, J.R., Clark, R. and Spitzer, A.R. (2007) The Changing Pattern of Necrotizing Enterocolitis. *Journal of Perinatology*, **27**, 9-13.
- [5] Ek, J.R., Bell, E.F., Nelson, R.A. and Radhi, M.A. (1999) Infrared Thermographic Calorimetry Applied to Preterm Infants under Radiant Warmers. *Journal of Thermal Biology*, **24**, 97-103. [https://doi.org/10.1016/s0306-4565\(98\)00044-8](https://doi.org/10.1016/s0306-4565(98)00044-8)
- [6] Mintzer, J.P., Parvez, B., Chelala, M. and Alpan, G. (2014) Impact of Sepsis on Perfusion Index in Neonates. *Journal of Perinatology*, **34**, 480-484.
- [7] Cresi, F., Pelle, E., Calabrese, R., Costa, L., Farinasso, D. and Silvestro, L. (2010) Perfusion Index Variations in Clinically and Hemodynamically Stable Preterm Newborns in the First Week of Life. *Italian Journal of Pediatrics*, **36**, Article No. 6. <https://doi.org/10.1186/1824-7288-36-6>

- [8] Granelli, A.D. and Östman-Smith, I. (2007) Noninvasive Peripheral Perfusion Index as a Possible Tool for Screening for Critical Left Heart Obstruction. *Acta Paediatrica*, **96**, 1455-1459. <https://doi.org/10.1111/j.1651-2227.2007.00439.x>
- [9] Lyon, A.J., Pikaar, M.E., Badger, P. and McIntosh, N. (1997) Temperature Control in Very Low Birthweight Infants during First Five Days of Life. *Archives of Disease in Childhood—Fetal and Neonatal Edition*, **76**, F47-F50. <https://doi.org/10.1136/fn.76.1.f47>
- [10] Miller, S.S., Lee, H.C. and Gould, J.B. (2011) Hypothermia in Very Low Birth Weight Infants: Distribution, Risk Factors and Outcomes. *Journal of Perinatology*, **31**, S49-S56. <https://doi.org/10.1038/jp.2010.177>
- [11] Adams, A.K., Nelson, R.A., Bell, E.F. and Egoavil, C.A. (2000) Use of Infrared Thermographic Calorimetry to Determine Energy Expenditure in Preterm Infants. *The American Journal of Clinical Nutrition*, **71**, 969-977. <https://doi.org/10.1093/ajcn/71.4.969>
- [12] Laughon, M., Bose, C., Allred, E.N., O'Shea, T.M., Van Marter, L.J., Ehrenkranz, R.A. and Leviton, A. (2009) Patterns of Illness in Extremely Preterm Infants. *American Journal of Obstetrics and Gynecology*, **201**, 500.e1-500.e8.
- [13] Dani, C., Pratesi, S., Fontanelli, G., Barp, J. and Bertini, G. (2010) Blood Perfusion Index in Preterm Infants during the First Week of Life. *Early Human Development*, **86**, 273-276.
- [14] Knobel, R.B., Holditch-Davis, D. and Schwartz, T.A. (2010) Optimal Body Temperature in Transitional Extremely Low Birth Weight Infants Using Heart Rate and Temperature as Indicators. *Journal of Obstetric, Gynecologic & Neonatal Nursing*, **39**, 3-14. <https://doi.org/10.1111/j.1552-6909.2009.01087.x>
- [15] Bingham, P.M., Ashikaga, T. and Abbasi, S. (2009) Prospective Study of Non-Nutritive Sucking and Feeding Skills in Premature Infants. *Archives of Disease in Childhood—Fetal and Neonatal Edition*, **95**, F194-F200. <https://doi.org/10.1136/adc.2009.164186>
- [16] Underwood, M.A. (2013) Human Milk for the Premature Infant. *Pediatric Clinics of North America*, **60**, 189-207. <https://doi.org/10.1016/j.pcl.2012.09.008>
- [17] Dollberg, S., Lusky, A. and Reichman, B. (2005) Patent Ductus Arteriosus, Indomethacin and Necrotizing Enterocolitis in Very Low Birth Weight Infants: A Population-Based Study. *Journal of Pediatric Gastroenterology and Nutrition*, **40**, 184-188. <https://doi.org/10.1097/00005176-200502000-00019>
- [18] Sahni, R., Schulze, K.F., Kashyap, S., Ohira-Kist, K., Myers, M.M. and Fifer, W.P. (1999) Body Position, Sleep States, and Cardiorespiratory Activity in Developing Low Birth Weight Infants. *Early Human Development*, **54**, 197-206. [https://doi.org/10.1016/s0378-3782\(98\)00104-2](https://doi.org/10.1016/s0378-3782(98)00104-2)
- [19] van Vonderen, J.J., Roest, A.A.W., Siew, M.L., Walther, F.J., Hooper, S.B. and te Pas, A.B. (2014) Measuring Physiological Changes during the Transition to Life after Birth. *Neonatology*, **105**, 230-242. <https://doi.org/10.1159/000356704>
- [20] Huizing, M.J. and Villamor, E. (2019) Temperature Regulation in Preterm Infants: A Review. *Journal of Perinatology*, **39**, 1131-1139.
- [21] Lima, A. and Bakker, J. (2005) Noninvasive Monitoring of Peripheral Perfusion. *Intensive Care Medicine*, **31**, 1316-1326. <https://doi.org/10.1007/s00134-005-2790-2>
- [22] El-Khuffash, A. and Molloy, E.J. (2008) Are Hemodynamic Biomarkers Useful in Neonatal Care? *Pediatric Research*, **64**, 236-240.
- [23] Kommers, D.R., Joshi, R., van Pul, C., Atallah, L., Feijs, L., Oei, G., et al. (2017) Fea-

- tures of Heart Rate Variability Capture Regulatory Changes during Kangaroo Care in Preterm Infants. *The Journal of Pediatrics*, **182**, 92-98. <https://doi.org/10.1016/j.jpeds.2016.11.059>
- [24] Tian, Y., Inocencio, I.M., Sehgal, A. and Wong, F.Y. (2025) Impact of Kangaroo Mother Care on Autonomic Cardiovascular Control in Foetal-Growth-Restricted Preterm Infants. *Pediatric Research*, **97**, 1983-1988. <https://doi.org/10.1038/s41390-024-03555-z>
- [25] Patel, R.M. and Denning, P.W. (2013) Therapeutic Use of Prebiotics, Probiotics, and Postbiotics to Prevent Necrotizing Enterocolitis: What Is the Current Evidence? *Clinics in Perinatology*, **40**, 11-25. <https://doi.org/10.1016/j.clp.2012.12.002>
- [26] Karlsson, V., Heinemann, A.B., Sjörs, G., Nykvist, K.H. and Ågren, J. (2012) Early Skin-to-Skin Care in Extremely Preterm Infants. *Acta Paediatrica*, **101**, 1002-1007.
- [27] Bergman, N.J., Linley, L.L. and Fawcus, S.R. (2004) Randomized Controlled Trial of Skin-to-Skin Contact from Birth. *Acta Paediatrica*, **93**, 779-785.
- [28] Boundy, E.O., Dastjerdi, R., Spiegelman, D., Fawzi, W.W., Missmer, S.A., Lieberman, E., *et al.* (2016) Kangaroo Mother Care and Neonatal Outcomes: A Meta-Analysis. *Pediatrics*, **137**, e20152238. <https://doi.org/10.1542/peds.2015-2238>
- [29] Schulzke, S.M., Deshpande, G.C. and Patole, S.K. (2007) Neurodevelopmental Outcomes of Very Low Birth Weight Infants. *Archives of Disease in Childhood*, **92**, F423-F428.
- [30] Gregory, K.E., DeForge, C.E., Natale, K.M., Phillips, M. and Van Marter, L.J. (2011) Necrotizing Enterocolitis in the Premature Infant. *Advances in Neonatal Care*, **11**, 155-164. <https://doi.org/10.1097/anc.0b013e31821baaf4>