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Kangaroo Mother Care with Integrated Sensors for Vital Sign Monitoring In Low Birth Weight Infants

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ABSTRACT

Background: Low birth weight (LBW) infants are at high risk of thermoregulatory, cardiovascular, and respiratory disorders, requiring accurate monitoring of vital signs. The limitations of continuous monitoring devices in healthcare facilities have prompted the development of sensor-based Kangaroo Mother Care (KMC) slings. This study aimed to assess the diagnostic accuracy of temperature, pulse rate (HR), and oxygen saturation (SpO_2) sensors on KMC slings compared to standard hospital medical devices. **Methods**: A cross-sectional comparative study was conducted on 31 LBW babies who underwent KMC treatment in the Perinatology room at Ampana Hospital from June to September 2025. Temperature, pulse, and SpO_2 measurements were simultaneously obtained using wearable sensors on KMC slings and standard devices, including clinical digital thermometers, neonatal multiparameter/ECG monitors, and medical pulse oximeters. The analysis includes sensitivity, specificity, and positive and negative predictive values. **Results**: The temperature sensor shows a sensitivity of 90.9% and a specificity of 66.7%. The HR sensor has a sensitivity of 77.8% and a specificity of 86.4%. The SpO_2 sensor shows a sensitivity of 88.0% and a specificity of 64.0%. These values demonstrate a fairly good abnormality detection rate, but still show limitations in consistently distinguishing normal physiological conditions from standard clinical devices. **Conclusion**: The sensor on the KMC sling shows moderate diagnostic performance and does not yet match the accuracy of standard clinical devices. Given the limitations of the design and sample size, these findings need to be interpreted with caution. These devices have the potential to be used as an initial monitoring or screening support tool in the context of KMC, but require further technical development and validation before wider implementation.

INTRODUCTION

The birth of babies with low birth weight (LBW), especially premature at the gestational age <37 weeks, is the dominant factor that has a risk of 5.87 times the risk of stunting. Birth weight is an important and reliable indicator of neonatal and infant survival, both in terms of physical growth and mental development. Birth weight can also serve as a general indicator of health, nutrition, and socioeconomic status. Indicators of a nation's health are still seen in the high or low infant mortality rate (Dhilon & Eldarita Fitri, 2019; Dinkes Sulawesi Tengah, 2021).

The highest risk of infant mortality occurs in the first 28 days of life (the neonatal period), with the global neonatal mortality rate of 17 per 1,000 live births in 2022. In Indonesia, AKB is recorded at 16 per 1,000 live births in 2024. These data confirm that the neonatal period, particularly in LBW babies, is a critical phase that is highly dependent on the stability of vital signs

(UNICEF, 2022). In Central Sulawesi Province, the number of neonatal deaths aged 0–28 days increased from 297 cases in 2021 to 308 cases in 2022. The main cause of neonatal mortality was LBW (27.92%), followed by asphyxia (19.16%) and hypothermia (Dinkes Sulawesi Tengah, 2021). This condition shows that the physiological instability of LBW babies is still a major challenge in neonatal services.

Kangaroo Mother Care (KMC) has been proven to be an effective evidence-based nonpharmacological intervention in improving the physiological stability of LBW infants, including regulating body temperature, heart rate, respiratory rate, and oxygen saturation, as well as supporting weight gain and mother-infant bonding (Utami S, 2019). The effectiveness of KMC is influenced by the duration of implementation, where the duration of two to four hours per day provides more optimal physiological results (Muliani & Lisnawati, 2018).

Although the clinical effectiveness of KMC has been well documented, most studies still focus on clinical outcomes without adequately addressing the technological aspects of vital sign monitoring during KMC (Purkayastha et al., 2025). In clinical practice, monitoring the baby's vital signs during Kangaroo Mother Care (KMC) implementation typically still uses standard hospital devices designed for general monitoring in intensive care units. These devices often use cables, sensors, and electrodes that can limit the mother's and baby's mobility and potentially interfere with the comfort or duration of skin-to-skin contact. This reflects an opportunity to develop vital signs monitoring technology that is more compatible with the dynamics of the KMC position and clinical needs as the practice progresses (Senechal, Radeschi, Kearney, & Anna, 2026).

In wearable neonatal monitoring (Wearable Neonatal Monitoring), various devices, such as the BEMPU TempWatch and the Neopenda system, have been developed to detect hypothermia and physiological instability in high-risk neonates. However, these devices have not been specifically validated in the context of the implementation of *Kangaroo Mother Care*, especially regarding the accuracy of vital mark measurements during skin-to-skin contact (Nimbalkar, Patel, & Patel, 2023).

In addition, scientific evidence on the accuracy of integrated KMC sensors compared to standard hospital tools, especially in the context of neonatal services in Indonesia, is still very limited. This gap underscores the need for diagnostic validation studies that assess the performance of KMC sensors as a safe, accurate, and compliant vital sign monitoring tool in accordance with KMC practices. Therefore, this study aims to assess the accuracy of *the Kangaroo Mother Care* (KMC) sensor in detecting the baby's vital signs, including body temperature, pulse, and oxygen saturation (SpO_2), compared to standard tools used in hospitals.

METHODS

Research Design and Location

This study uses a diagnostic accuracy design with a cross-sectional approach, in which the baby's vital signs are measured simultaneously using two devices: the KMC sensor as the index test and the hospital medical device as the gold standard. Measurements are taken simultaneously to minimize temporal bias between the test instrument and the comparator. This study is a pilot study with the main objective of evaluating the technical feasibility, measurement stability, and initial estimates of the diagnostic accuracy parameters of the KMC sensor. The research was carried out in the Perinatology Room of Ampana Hospital, Ampana Kota District, Tojo Una-Una Regency, Central Sulawesi, in the period of June-September 2025.

Population and Sample

The study population was all infants who underwent treatment with the KMC method in the Perinatology room of Ampana Hospital. The study sample consisted of infants who met the following inclusion and exclusion criteria:

Inclusion criteria:
1. Infants with low birth weight and/or infants undergoing KMC treatment
2. Stable clinical condition based on the assessment of the doctor/nurse in charge
3. Obtain written consent from a parent or guardian (*informed consent*)

Exclusion criteria:

1. Infants with congenital abnormalities that affect the cardiovascular or respiratory system
2. Babies in critical condition requiring intensive intervention

The sample size was 31 babies, designated as a pilot study. This sample size is not intended for high-precision estimation, but rather to assess the technical feasibility, signal stability, and initial variation in accuracy parameters of the KMC sensor before conducting large-scale studies. Therefore, the diagnostic accuracy results in this study were interpreted exploratively, and confidence intervals were reported to emphasize the degree of uncertainty in the estimates.

The sample size is not intended for conclusive hypothesis testing but rather to obtain preliminary estimates of sensitivity, specificity, and confidence intervals as a basis for planning larger-scale follow-up studies and for recommendations in early-stage diagnostic research.

Sampling Technique

Sampling was carried out using consecutive sampling, i.e. all infants who met the inclusion criteria and did not meet the exclusion criteria were recruited sequentially during the study period.

Research Variables

1. Independent variables (test kit): KMC sensor measurement results (body temperature, pulse, and oxygen saturation/SpO_2)
2. Dependent variables (gold standard): results of hospital standard medical device measurements (temperature, pulse, SpO_2)

Instrument and Device Specifications

The research instruments include: KMC sensor (test kit) in the form of a vital sign sensor integrated into the KMC sling, used to record body temperature, pulse, and oxygen saturation of the baby. These sensors are installed at the same anatomical location in each infant, according to the research protocol, to reduce placement variability.

1. The KMC sensor was developed as a modular prototype assembled from multiple multi-source sensor components, so it does not use a single brand at this stage of the study.
2. Hospital standard devices (gold standard) include:
   a. Medical Digital Thermometer
   b. Neonatal vital signs monitor
   c. Medical Pulse Oximeter

   All gold standard devices are clinical tools that are routinely used in the Perinatology room and are in an active calibration status according to hospital procedures
3. Data logging sheet to record measurement results from both devices simultaneously.

Measurement and Validation Procedures

Prior to data collection, the baby's parents were given an explanation of the study's purpose and procedure, then asked to sign an informed consent form. Infants who met the inclusion criteria then followed the KMC treatment procedure equipped with sensors, and were monitored and the results of KMC sensor measurements were simultaneously recorded with vital signs examination equipment at the hospital for 2 hours of treatment. Vital sign measurements are obtained simultaneously using KMC sensors and hospital-standard devices to minimize time bias. KMC sensor readings are recorded at the same time as, or within ±30 seconds of, the gold standard measurement, when the infant is in a stable state, so that the comparison of results reflects equivalent physiological conditions. Prior to data collection, the KMC sensor undergoes an initial calibration per the manufacturer's instructions. Measurements were carried out in a controlled clinical environment with stable room temperature and infant position according to KMC principles.

Diagnostic Threshold

The measurement results of both devices were categorized as normal and abnormal based on the neonatal clinical reference limits routinely used in the perinatology unit. Infant body temperature is categorized as abnormal when the temperature value is <36.5 °C or >37.5 °C. Normal: 36.5–37.5 °C. Heart rate (HR) is considered abnormal if it is <100 or >160 beats per minute. Normal: 100–160 x/m. Oxygen saturation (SpO_2) is categorized as abnormal when the value is <90%, and the SpO_2 value of ≥90% is classified as normal.

Data Analysis

Data analysis was carried out using the following diagnostic accuracy tests:

1. Preparation of a 2×2 contingency table for each vital sign parameter (temperature, pulse, and SpO_2) between the KMC sensor and the gold standard
2. Calculations of sensitivity, specificity, PPV, NPV, likelihood ratio, total accuracy, and AUC ROC to assess the censor's discriminating ability
3. All estimates were reported with a 95% confidence interval (95% CI), sensitivity and specificity ≥ 80%, to emphasize the uncertainty of estimates due to small sample sizes
4. The analysis was carried out using computerized statistical software

RESULTS

This study involved 31 low-birth-weight infants who received Kangaroo Mother Care (KMC) in the Perinatology Room at Ampana Hospital. The characteristics of the infants and mothers are presented to describe the clinical and demographic profile of the study participants before evaluating the diagnostic accuracy of the KMC sling-integrated vital sign sensors. The variables included birth weight category, birth length, infant sex, gestational age at birth, maternal parity, and the age at which KMC was initiated. These characteristics are important because physiological maturity, birth weight, and timing of KMC initiation may influence the stability of vital signs and the performance of sensor-based monitoring during KMC.

Table 1. Frequency Distribution of Low Birth Weight (LBW) Infant Characteristics Receiving Kangaroo Mother Care

Variables	n	%
Birth Weight		
LBW (Low Birth Weight Infants)	25	80.6
VLBW (Very Low Birth Weight Infants)	6	19.4
Birth Length		
≥ 48 cm	3	9.7
< 48 cm	28	90.3
Baby's Gender		
Male	11	35.5
Female	20	64.5
Gestational Age at Birth		
Term	7	22.6
Preterm	24	77.4
Parity		
Primipara	10	32.3
Multipara	17	54.8
Grande Multipara	4	12.9
KMC Starting Age		
< 7 days	4	12.9
7-15 days	21	67.7
> 15 days	6	19.4

Based on the table above, most babies (80.6%) belong to the LBW category, with a total of 25 babies, while the BBLSR category has 6 babies (19.4%). For Birth Body Length, almost all babies (90.3%) had a birth length of <48 cm, while only 3 babies (9.7%) had a birth length of ≥48 cm. LBW births are dominated by females (64.5%) compared to male babies (35.5%). Likewise, the gestational age of most preterm babies was born (77.4%), while the term was only 22.6%. The majority of babies were born to multiparous mothers (54.8%), followed by primiparous mothers

(32.3%) and grand multiparous mothers (12.9%). The majority of infants who started KMC treatment were at 7–15 days of age (67.7%), while only 12.9% started KMC at <7 days of age and 19.4% after >15 days of age.

Table 2. Comparative Test of the Accuracy Test of LBW Vital Sign Sensor Integrated on KMC Sling Compared to Gold Standard Based on Measurements: Temperature, Pulse, SpO2

Parameters Sensors	TP	FP	FN	TN	Or (%)	Sp (%)	PPV (%)	NPV (%)	AUC (Category)	CI 95% (Or)	CI 95% (Sp)
Temperature	20	3	2	6	90.9	66.7	87.0	75.0	83.9% (Sufficient)	72.2–97.5	35.4–87.9
Pulse	7	3	2	19	77.8	86.4	70.0	90.5	83.9% (Sufficient)	45.3– 93.7	66.7–95.3
SpO2	15	5	2	9	88.0	64	75.0	81.8	77.4% (Sufficient)	65.7– 96.7	38.8–83.7

TP: True Positive; FP: False Positive; FN: False Negative; TN: True Negative; Or: Sensitivity; Sp: Specificity; PPV: Positive Predictive Value; NPV: Negative Predictive Value; AUC: Area Under the Curve

Based on Table 2 and the results of the accuracy analysis, the temperature and SpO_2 sensors show high sensitivity (90.9% and 88.0%, respectively) and AUCs in the sufficient range, indicating they are both effective as screening and early detection tools for identifying abnormal conditions during KMC implementation. The consistency of temperature sensor detection capabilities is reflected in the narrow, high-sensitivity confidence intervals (CIs) (72.2–97.5%), although the wide specificity CI (35.4–87.9%) indicates uncertainty in recognizing normal conditions due to the limited number of normal samples. SpO_2 sensors also support early warning functions with relatively high sensitivity (65.7–96.7%), but lower specificity and wider CIs indicate a potential for false alarms, so positive results need to be confirmed using standard gold devices. In contrast, pulse sensors showed high specificity (86.4%) and excellent NPV (90.5%), with narrower specificity CI (66.7–95.3%), indicating better ability to identify and confirm normal physiological conditions and minimize false positives. Overall, the combination of these three sensors complements each other: the temperature and SpO_2 sensors play a major role in early detection, while pulse sensors are more effective at confirming normal conditions during KMC monitoring.

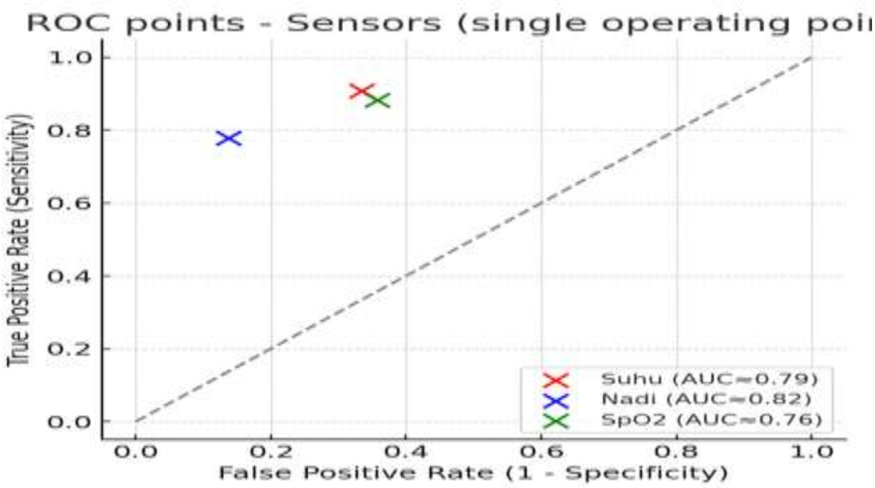

Figure 1. Receiver Curve Operating Characteristic (ROC) Temperature, Pulse, and SpO_2 Sensor

The graph above shows the Receiver Operating Characteristic (ROC) curve for each sensor. The ROC plot shows a diagonal line at 0.5 for a random cut-off, while all three sensors show AUCs above 0.75, indicating fairly good discriminating performance. The differences in AUC values across sensors indicate variation in the KMC system's ability to detect physiological changes. The pulse sensor showed stable performance, while the temperature and SpO_2 sensors still showed limitations that were likely affected by motion artifacts, sensor position variations, and environmental factors during KMC implementation

DISCUSSION

Respondent Characteristics

The results showed that most babies belonged to the LBW category (80.6%), compared with BBLSR (19.4%). This condition is in line with the WHO report, which confirms that more LBW babies can undergo KMC than BBLSR because babies with very low birth weight often require intensive care in the NICU room before KMC can be implemented (World Health Organization, 2020). This indicates that the birth of BBLSR is more likely to experience comorbidity complications than LBW so that KMC can be implemented more easily and faster in babies with higher birth weight and more stable clinical conditions. Likewise, with Birth Body Length (PBL), most babies (90.3%) have a PBL of <48 cm. These results are consistent with the research, which found that birth length is closely related to fetal maturity status, where premature babies generally have shorter body lengths than preterm babies (Jamshed, Khan, Chohan, Bano, & Shahnawaz, 2020).

For Gender, there are more female babies (64.5%) than males (35.5%). The global literature reports gender differences in neonatal morbidity, with premature male infants more prone to respiratory complications and higher mortality than females (Alur, Holla, & Hussain, 2024). However, in this study, the proportion of baby girls was higher, possibly due to local variations or sample selection factors, and the sample was small because it was still a pilot study. Gestational age at birth was mostly preterm births (77.4%), confirming that prematurity was the dominant factor in the occurrence of LBW. WHO reports that more than 70% of global LBW cases are caused by preterm births (World Health Organization (WHO), 2019). The results of this study are consistent with global data.

Regarding Maternal Parity, the majority of babies were born to multipara mothers (54.8%), followed by primipara (32.3%) and grande multipara (12.9%). Some literature states that primiparae are at a higher risk of giving birth to LBW babies due to the adaptation of the first pregnancy (Lin, Lu, Chen, Li, & Guo, 2021). However, in this study, multiparous women predominated, which may be associated with cumulative risk factors in subsequent pregnancies, such as short pregnancy intervals, maternal nutritional conditions, or the presence of comorbidities. The importance of follow-up research is the need to look at the history of previous pregnancies, which allows the association of multiparous mothers who give birth to LBW to be followed by a history of previous childbirth with premature birth.

Most infants started KMC at 7–15 days (67.7%), followed by >15 days (19.4%) and <7 days (12.9%). This condition indicates that most LBW babies do not get KMC immediately from the beginning, but rather after one week of birth. Research by Charpak et al. (2021) suggests that KMC started early (<7 days) is associated with increased success in maintaining body temperature, increased growth, and decreased neonatal mortality. Studies by Mazumder et al. show that early implementation of KMC (<7 days) can significantly reduce neonatal mortality (Mazumder S, Taneja S, Dube B, Bhatia K, Ghosh R, Shekhar M, 2019). However, in practice, many factors affect the delay in implementing KMC, including the baby's clinical condition, maternal readiness, and health facility policies. According to neonatal care theory, KMC should ideally be started as early as possible after the baby's condition is stable, even advocating KMC immediately after birth for LBW that does not require intensive care. This shows the need for policies to encourage early initiation of KMC in stable LBW infants (World Health Organization (WHO), 2021).

Accuracy of LBW Vital Sign Sensor Integrated on KMC Sling Compared to Gold Standard Based on Temperature, Pulse, SpO2 Measurements

1. **Temperature**

   The results of this study show that the temperature sensor integrated into the Kangaroo Mother Care (KMC) carrier has high sensitivity (90.9%) for detecting changes in body temperature in low-birth-weight babies (LBW), enabling most cases of hypothermia or hyperthermia to be identified. These findings are clinically relevant because delayed detection of hypothermia in LBW is known to be associated with an increased risk of apnea, metabolic disorders, hypoglycemia, and neonatal mortality (Giliyaru, Bhanu Hruday Reddy, & E, 2023). However, a relatively moderate specificity value (66.7%) confirms a trade-off between sensitivity and the sensor's ability to confirm normal temperature conditions, so this performance cannot be interpreted as high diagnostic accuracy. Thus, the portrayal of temperature sensors as "good enough" devices should be limited to early detection, not as a definitive diagnostic tool, given the still significant proportion of false-positive results. In clinical practice, these false positive results have implications to consider, especially in facilities with limited resources, as they can trigger alarm fatigue (*Alarm fatigue*), increase the workload of health workers, and have the potential to cause additional interventions that are not needed if not accompanied by confirmation with standard hospital tools.

Compared to hospital clinical thermometers, which have minimal fault tolerance (±0.1–0.2°C), wearable-based temperature sensors on KMC slings are more susceptible to external factors such as the baby's position during skin-to-skin contact, movement, ambient temperature, and the quality of sensor-to-skin contact. This vulnerability is an inherent challenge for wearable monitoring technology and is one of the main explanations for the low specificity observed, as has also been reported in previous neonatal temperature monitoring devices. Studies evaluating Neonatal Temperature Monitors, Bluetooth thermometers, and TempWatch monitors have consistently shown that while wearable devices can improve the frequency of hypothermic detection, their performance is still influenced by the context of use and is not yet fully on par with standard clinical devices (Sosa Saenz et al., 2020).

Another study also explained that continuous temperature monitoring with a Bluetooth thermometer in neonates was shown to be comparable to a digital thermometer and was effective in detecting hypo/hyperthermia early, even though false alarms were still present (Chandrasekaran, Ashok & Abiramalatha, et, 2018). A study in Ghana using the wearable BEMPU TempWatch showed that the device has a sensitivity of about 67.8% and a specificity of about 95.9% in detecting neonatal hypothermia, indicating an increase in detection frequency compared to manual examinations, although its performance is not fully comparable to standard digital clinical tools (Garvs, Genzel-Boroviczény, Phiri, & Schultz, 2024; McAbee et al., 2023).

Babies with low birth weight have brown fat tissue that has not developed optimally, a relatively larger body surface area than their weight, and an immature central nervous system. These factors make LBW more easily lose heat through conduction, convection, evaporation, and radiation mechanisms (Guyton, 2020). Therefore, maintaining body temperature stability is a top priority in LBW treatment. Concept *neutral thermal environment (NTE)* states that the baby must be in environmental conditions with optimal temperature so that energy and oxygen are not wasted on the thermoregulatory process (Wood, Johnson, Temples, & Bordelon, 2022).

The use of a temperature sensor integrated into the Kangaroo Mother Care (KMC) sling has significant meaning. A pilot study in India shows that the use of wearable sensors mounted on babies during KMC allows continuous and real-time monitoring of temperature and position without the need to disturb the baby's position in a sling (Rao, Thankachan, Amrutur, Washington, & Mony, 2018). Similar findings were also reported from trials using the TempWatch device, which not only aided in the detection of hypothermia but also increased the duration of KMC and supported weight gain in LBW infants (Balogun et al., 2023).

Physiologically, LBW's vulnerability to heat loss due to the immaturity of the thermoregulatory system and the greater proportion of body surface area makes temperature monitoring an important component of neonatal care. In this context, integrating temperature sensors into KMC slings can serve as a supporting alternative in LBW treatment, allowing health workers to continuously monitor the baby's vital signs without interrupting KMC. This approach has the potential to support the continuity of skin-to-skin contact, increase maternal involvement in monitoring the baby's condition, and facilitate early detection of temperature changes during KMC.

However, in implementing Kangaroo Mother Care (KMC)-based temperature sensors, it is necessary to consider feasibility in clinical practice, including device limitations, potential additional costs, and the service system's readiness to respond to generated alarms. This study also has methodological limitations, including the lack of blinding of observers and control groups, which may lead to measurement bias. In addition, variations in sensor mounting positions, including differences in anatomical location, skin contact consistency, sling pressure, and mother and baby movement during KMC, can affect the stability of temperature readings. Environmental factors, including fluctuations in room temperature, exposure to outside air when the carrier is opened, variations in mother-infant skin contact, and the baby's condition during measurement, can also act as disruptive factors. Therefore, the findings of this study are considered preliminary and exploratory evidence and cannot be generalized as a substitute for standard hospital tools. However, this KMC sensor is designed as an adaptive device and will continue to be developed through design refinement, standardization of installation protocols, and larger-scale testing, so that it is hoped that at the next stage it can be used more widely as a support tool for monitoring neonatal temperature in clinical practice.

2. Pulse

The results of this study showed that the pulse sensor integrated in the Kangaroo Mother Care (KMC) carrier had a sensitivity of 77.8% and a specificity of 86.4% in detecting heart rate abnormalities in low-birth-weight infants (LBW). Current sensitivity values indicate that although most abnormal pulse events can be detected, nearly one in four cases are potentially missed (false negative), so this sensor cannot be relied upon as the only detection tool. This condition has important clinical implications because the delay in recognizing bradycardia or tachycardia in LBW can be related to hypoxia, infection, metabolic disorders, or physiological stress. Therefore, the pulse sensor reliability claim needs to be understood proportionately, given that the sensitivity of 77.8% still leaves a risk of detection failure in some babies with abnormal pulses. On the other hand, the relatively high specificity (86.4%) and the Negative Predictive Value (NPV) of 90.5% indicate that when the sensor indicates a normal pulse, the results are generally reliable. However, a Positive Predictive Value (PPV) of 70% indicates that a large proportion of results are false positives, which can lead to excessive vigilance, unnecessary re-examinations, or anxiety in mothers and health workers if the results are not confirmed with standard tools.

Compared to ECG electrode-based hospital heart monitors or clinical pulse oximeters, pulse sensors on KMC slings have inherent accuracy limitations (Scardulla et al., 2023). The photoplethysmography (PPG) technology used is simpler and relies heavily on signal quality, so it is easily affected by motion artifacts, low peripheral perfusion, and variations in sensor placement (Ghamari, 2018; Park, Seok, Kim, & Shin, 2022). This limitation in correcting motion artifacts is a well-known weakness of PPG devices and a major factor in false negatives and false positives, especially in neonates who are actively moving during KMC.

Previous literature indicates that PPG sensors are feasible for neonatal heart rate monitoring in communities or primary facilities, but their consistency remains lower than that of hospital devices. Validation studies of various portable monitors showed a heart rate deviation of about 5–10 beats per minute compared to standard ECGs, which is still clinically acceptable for initial monitoring, but not for in-depth diagnosis, enforcement, or assessment of heart rhythm (Knight et al., 2023). Thus, the literature collectively confirms that the main strengths of PPG sensors lie in accessibility and continuous monitoring, not in high precision. (Pinge, Bandyopadhyay, Ghosh, & Sen, 2022; Weiler, Villajuan, Edkins, Cleary, & Saleem, 2017).

Physiologically, LBW infants have a more labile heart rate due to immaturity of the autonomic nervous system, leading to greater pulse fluctuations than in full-term infants (Smolkova, Sekar, Kim, Sunwoo, & El-Dib, 2025). Sensor integration on the KMC sling can serve as a supportive alternative, helping healthcare workers continuously monitor the baby's vital signs without interrupting KMC. This approach has the potential to strengthen family involvement in early observation of the baby's condition and to allow early detection of changes that require further evaluation. However, implementing KMC-based pulse sensors also poses challenges in data interpretation, the risk of alarm misinterpretation, limited power and device maintenance, and the readiness of the referral system if abnormal results are found. Overall, the pulse sensor on the KMC sling is more appropriately positioned as an early monitoring tool and an early warning system that is complementary, with the main benefit of ensuring the stable condition of the baby during KMC, but with full awareness of the sensitivity limitations and risks of motion artifacts inherent in PPG technology

3. **SpO_2**

The results of this study showed that the SpO_2 sensor integrated in the Kangaroo Mother Care (KMC) sling had high sensitivity (88%) with lower specificity (64%). These findings indicate that most hypoxemia events can be detected by sensors, but distinguishing normocemic conditions remains limited, resulting in a clear trade-off between sensitivity and specificity. In the clinical context of LBW, high sensitivity is particularly important because failure to recognize hypoxemia can be fatal. However, the low specificity also means that about one-third of the measurement results are potentially false positives, which need to be interpreted carefully.

A false positive rate of about 36% has clinical implications that cannot be ignored, especially in low-resource settings, as it can trigger alarm fatigue, anxiety in the mother, and increased follow-up examinations that are not necessarily necessary. Therefore, the SpO_2 sensor on the KMC sling cannot be used as a diagnostic tool but rather as an initial monitoring tool to identify infants who require further evaluation with a standard pulse oximeter.

This difference in performance aligns with the characteristics of photoplethysmography (PPG) technology used in wearable sensors, which are known to be more susceptible to motion artifacts, peripheral perfusion variations, and poor sensor-skin contact. The findings reinforce the consensus that portable SpO_2 devices have major uses in early detection, but have not yet matched the precision of hospital devices equipped with more advanced signal processing algorithms and alarm systems (Kyriacou, 2023; Scardulla et al., 2023).

The results of this study are consistent with previous findings that portable pulse oximeters in healthcare facilities with limited resources can effectively detect hypoxemia. However, measurement accuracy is often affected by physiological and technical factors, including infant movements and low peripheral perfusion (Al-Beltagi, Saeed, Bediwy, & Elbeltagi, 2024). Another study also evaluated the diagnostic accuracy of a portable pulse oximeter integrated with a smartphone in neonates, although portable devices can be used for early monitoring, they are still less sensitive than hospital devices in detecting critical clinical events (Travers et al., 2025).

Physiologically, the oxygen saturation of newborns increases gradually in the first hours of life. After respiratory adaptation, the normal value of oxygen saturation ranges from 90–95% (Guyton, 2020). Oxygen saturation below 90% indicates hypoxemia that must be treated immediately, because prolonged hypoxemia can trigger impaired brain growth, increase the risk of seizures, and cause multiple organ failure. In LBW, the susceptibility to hypoxemia is higher than in full-term infants. This is influenced by pulmonary immaturity, the risk of respiratory distress syndrome, and lower oxygen reserve capacity. Therefore, continuous monitoring of oxygen saturation is an important aspect in LBW treatment (Lien, 2020).

From an implementation perspective, the SpO_2 sensor integrated into KMC provides an alternative for monitoring that enables mothers and healthcare workers to continue observing the baby's vital signs without disrupting skin-to-skin contact. However, the feasibility of implementation in primary and community services needs to be considered in terms of user training needs, the interpretation of appropriate results, and the availability of referral systems for clinical confirmation. In addition, the interpretation of this study's results needs to be limited by its study design, which does not include gauge blinding, control groups, or graded analysis by birth weight categories, which may affect the estimation of sensor accuracy. Taking these factors into account, the SpO_2 sensor on the KMC sling is more appropriately seen as a supporting component in the LBW continuous monitoring strategy and will continue to be developed so that it can be used, especially in areas with limited health facilities, as well as being a complement in the strategy to reduce infant mortality

CONCLUSION

The conclusion of this study shows that the vital sign sensor integrated into the Kangaroo Mother Care (KMC) sling has moderate diagnostic capabilities and does not match the accuracy of standard hospital tools, especially in terms of specificity. Temperature and SpO_2 sensors exhibit relatively high sensitivity but limited ability to distinguish normal conditions, whereas pulse sensors show better specificity but suboptimal sensitivity. This performance variation across sensors confirms that the device cannot yet be positioned as a standalone diagnostic tool. Given the pilot study design, small sample size, and other methodological limitations, the results cannot be generalized as a substitute for conventional clinical tools. However, this device can be used, albeit in a limited capacity, as an early warning system to detect abnormal conditions in low-birth-weight babies, especially in health facilities with limited resources. Advanced research with a controlled design, larger sample sizes, and stratified analyses is required before considering broader clinical implementation.

Author's Contribution Statement: Muliani: Conceptualization, Methodology, formal analysis, **Abd. Farid**: Data curation, Writing- Original draft preparation, **Sarliana**: Writing–Reviewing and Editing.

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