

ORIGINAL

Development and Validation of the Digital Sensor Kariasa (SenDiKa 1.0 & 2.0): A Non-Invasive Prototype for Simultaneous Measurement of Blood Pressure, Blood Glucose, and Cholesterol

Desarrollo y Validación del Sensor Digital Kariasa (SenDiKa 1.0 & 2.0): Un Prototipo No Invasivo para la Medición Simultánea de la Presión Arterial, Glucosa y Colesterol

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ABSTRACT

Introduction: recurrent stroke remains one of the leading causes of morbidity and mortality worldwide. Monitoring key metabolic and cardiovascular risk factors—blood pressure, blood glucose, and cholesterol—typically requires invasive and separate measurements. This study presents the development and validation of a portable non-invasive device, the Digital Sensor Kariasa (SenDiKa 1.0), designed to simultaneously measure these three parameters using infrared technology.

Method: the prototype was developed through a multi-stage process: (1) literature review and selection of a 1200 nm infrared sensor, imported due to limited regional availability; (2) integration with KY-039 module and Arduino UNO microcontroller; (3) determination of zero offset (value 849) for signal calibration; (4) progressive calibration through 70 experimental measurements (October-December 2019), applying linear regression to establish predictive equations; and (5) validation through 264 measurements compared with standard invasive devices. Sensitivity and specificity were analyzed using chi-square tests.

Results: final equations demonstrated strong correlation with standard values, achieving coefficients of determination up to 0,9455. Validation results showed high sensitivity and specificity: blood pressure (94,5 % and 72,7 %), blood glucose (96,3 % and 79,4 %), and cholesterol (64,5 % and 89,4 %). The prototype was portable (15 × 9 × 4 cm), powered by 12V 1.2A, with real-time results displayed on a 2,4” LCD.

Conclusions: SenDiKa 1.0 successfully demonstrated the feasibility of a non-invasive, portable device for simultaneous measurement of three major stroke risk factors, with good sensitivity and specificity. While blood pressure and glucose achieved excellent agreement with manual methods, cholesterol measurement requires further refinement. This prototype has potential applications in primary care, community health screening, and home monitoring.

Keywords: Non-Invasive Sensor; Infrared Technology; Blood Glucose; Cholesterol; Blood Pressure; Stroke Prevention.

RESUMEN

Introducción: el accidente cerebrovascular recurrente sigue siendo una de las principales causas de morbilidad y mortalidad en el mundo. El control de factores de riesgo metabólicos y cardiovasculares—presión arterial, glucosa y colesterol—generalmente requiere mediciones invasivas y separadas. Este estudio

presenta el desarrollo y validación de un dispositivo portátil no invasivo, el Sensor Digital Kariasa (SenDiKa 1.0), diseñado para medir simultáneamente estos tres parámetros mediante tecnología infrarroja.

Método: el prototipo se desarrolló en varias etapas: (1) revisión bibliográfica y selección de un sensor infrarrojo de 1200 nm, importado por la limitada disponibilidad regional; (2) integración con el módulo KY-039 y el microcontrolador Arduino UNO; (3) determinación del “zero offset” (valor 849) para la calibración de señales; (4) calibración progresiva mediante 70 mediciones experimentales (octubre-diciembre 2019), aplicando regresión lineal para establecer ecuaciones predictivas; y (5) validación mediante 264 mediciones comparadas con dispositivos invasivos estándar. La sensibilidad y especificidad se analizaron con pruebas chi-cuadrado.

Resultados: las ecuaciones finales demostraron una fuerte correlación con los valores estándar, alcanzando coeficientes de determinación de hasta 0,9455. Los resultados de validación mostraron alta sensibilidad y especificidad: presión arterial (94,5 % y 72,7 %), glucosa (96,3 % y 79,4 %) y colesterol (64,5 % y 89,4 %). El prototipo fue portátil (15 × 9 × 4 cm), alimentado por 12V 1.2A, con resultados en tiempo real mostrados en una pantalla LCD de 2,4”.

Conclusiones: SenDiKa 1.0 demostró con éxito la viabilidad de un dispositivo portátil no invasivo para la medición simultánea de tres factores de riesgo principales de accidente cerebrovascular, con buena sensibilidad y especificidad. Mientras que la presión arterial y la glucosa mostraron una excelente concordancia con los métodos manuales, la medición de colesterol requiere mayor refinamiento. Este prototipo tiene aplicaciones potenciales en atención primaria, cribado comunitario y monitoreo domiciliario.

Palabras clave: Sensor no Invasivo; Tecnología Infrarroja; Glucosa; Colesterol; Presión Arterial; Prevención de Accidente Cerebrovascular.

INTRODUCTION

Stroke remains one of the leading causes of death and long-term disability worldwide, representing a major burden on healthcare systems and communities.^(1,2) Recurrent stroke, in particular, is associated with high mortality and significant deterioration in quality of life.^(3,4) Preventive strategies emphasize early detection and continuous monitoring of cardiovascular and metabolic risk factors such as arterial hypertension, diabetes mellitus, and dyslipidemia.⁽⁵⁾ These three conditions are recognized as the most prevalent and modifiable determinants of stroke recurrence.

Conventional methods for assessing blood pressure, blood glucose, and cholesterol typically rely on invasive techniques or separate devices.⁽⁶⁾ Blood glucose and cholesterol levels are most often measured through blood sampling and laboratory analysis, which can be time-consuming, require trained personnel, and may generate discomfort for patients.⁽⁵⁾ Blood pressure is usually monitored using cuff-based sphygmomanometers, which, although non-invasive, are limited to a single parameter and may not be practical for continuous or integrated screening. The lack of a portable, non-invasive, and multi-parameter device creates a barrier to large-scale community screening and home-based monitoring, especially in low-resource settings.

Recent advances in infrared (IR) spectroscopy and photoplethysmography (PPG) have demonstrated the potential to detect variations in tissue composition, blood flow, and biochemical markers without penetrating the skin.^(7,8) The use of infrared sensors within specific wavelength ranges enables the estimation of glucose and lipid concentrations based on light absorption characteristics of biomolecules.⁽⁸⁾

Similarly, optical sensors integrated with microcontrollers can detect pulsatile blood volume changes, allowing indirect calculation of blood pressure.⁽⁹⁾ Despite promising research, most prototypes described in the literature focus on a single parameter (for instance, glucose only) and are often limited by portability, calibration, or cost constraints.

To address these gaps, we developed the Digital Sensor Kariasa (SenDiKa 1.0 & 2.0), a prototype device capable of simultaneously measuring blood pressure, blood glucose, and cholesterol using a single non-invasive sensor platform. The system integrates a 1200 nm infrared sensor with an Arduino UNO microcontroller and a dedicated calibration algorithm, displaying results in real-time through an LCD interface.

The development of SenDiKa 1.0 & 2.0 followed a structured process including sensor selection, determination of zero offset, progressive calibration with invasive gold-standard devices, and validation of sensitivity and specificity.

This study reports the design, development, calibration, and validation of SenDiKa 1.0 and the modification design of SenDiKa 2.0. We hypothesize that the device can provide accurate and reliable measurements of three key stroke risk factors in a rapid, user-friendly, and portable format. By combining engineering innovation with clinical needs, SenDiKa 1.0 & 2.0 aims to contribute to improved stroke prevention strategies, particularly in community health programs and home-care monitoring.

METHOD

Study Design

This study followed an experimental design focused on the development, calibration, and validation of a non-invasive prototype, the Digital Sensor Kariasa (SenDiKa 1.0). The process comprised four phases: (1) sensor selection and hardware integration, (2) determination of zero offset, (3) calibration of measurement equations against invasive gold-standard devices, and (4) validation of sensitivity and specificity.

Sensor Selection and Hardware Configuration

A literature review was first conducted to identify sensors suitable for non-invasive detection of blood glucose and cholesterol. Based on published studies examining infrared absorption spectra of biological molecules, a wavelength of approximately 1200 nm was selected because it falls within the near-infrared region that demonstrates high sensitivity to variations in glucose and lipid concentrations and can also detect changes in tissue blood perfusion relevant to blood pressure estimation.^(5,10) The sensor and its receiver were imported from a manufacturer in New Jersey, United States, due to limited availability in Asia. To enable functional integration, the IR sensor was embedded in a KY-039 module, replacing the original photodiode with the 1200 nm IR emitter and receiver pair.

The sensor module was connected to an Arduino UNO R3 microcontroller using analog input (A0) for signal capture. The 2.4-inch TFT LCD display (model ILI9341, SPI interface) was used to visualize output in real time. The system was programmed in C/C++ using Arduino IDE version 1.8.19, and data were processed via serial communication for calibration. Power was supplied through a 12V, 1.2A DC adaptor. The source code and circuit schematics are available upon request to ensure reproducibility.

Determination of Zero Offset

To establish a baseline reference value, repeated baseline measurements were conducted using a standard opaque silicone calibration block (1,5 cm thickness) at room temperature ($25 \pm 1^\circ\text{C}$) under controlled lighting (500 lux). The zero offset value of $849 \pm 6,2$ (mean $\pm$ SD, $n = 30$ readings) was established after repeated measurements using the calibration block. This value was embedded in the Arduino code as the baseline reference for subsequent analog readings. The sensor output stabilized at values around 849, which was defined as the zero offset. This value was embedded in the Arduino sketch so that subsequent readings were adjusted accordingly. Additional shielding was applied around the sensor-receiver pair to minimize interference from ambient light.

Calibration Procedure

1. *Initial Calibration (October-November 2019)*
 - A total of 27 paired measurements were collected for blood glucose, cholesterol, and blood pressure (systolic and diastolic).
 - SenDiKa 1.0 readings were compared with values obtained using invasive reference devices (glucometer, lipid analyzer, sphygmomanometer).
 - Linear regression was applied to establish initial predictive equations.
2. *Expanded Calibration (December 2019)*
 - An additional 43 participants were recruited during a community health event at Depok Town Square.
 - For each participant, blood glucose, cholesterol, systolic, and diastolic blood pressure were recorded simultaneously with SenDiKa 1.0 and reference devices.
 - Data filtering was performed using a Z-score criterion ($|z| > 3$) to identify statistical outliers, and moving average smoothing (window = 5 readings) was applied to reduce high-frequency noise before regression modeling.
 - A final linear regression model was developed for each parameter—glucose, cholesterol, and blood pressure—using the same functional form ($Y = a \cdot X + b$, where X is the offset-corrected analog signal). Separate coefficients (a and b) were computed for each parameter based on calibration datasets.
 - The final predictive models were uploaded to the Arduino UNO for automated computation of results.

Validation of Sensitivity and Specificity

A validation study was performed using 264 paired measurements. For each parameter (blood pressure, glucose, cholesterol), results from SenDiKa 1.0 were classified as normal or high according to established clinical thresholds, and compared with classifications from reference invasive methods.

Statistical Analysis

- Sensitivity (true positive rate) and specificity (true negative rate) were calculated.
- Agreement between SenDiKa 1.0 and reference devices was evaluated using Cohen's kappa coefficient (κ), which quantifies the level of concordance beyond chance. The kappa values were interpreted following Landis and Koch (1977) criteria, where $\kappa > 0,60$ indicates substantial agreement.
- Sensitivity and specificity values above 60 % were considered acceptable for prototype validation.

Ethical Considerations

Ethical approval for the study was obtained from the Research Ethics Committee of National Research and Innovation Agency (Approval No. Ref. 031/KE.03/SK/02/2024). All participants provided written informed consent prior to data collection.

RESULTS

Prototype Development SenDiKa 1.0

The final version of the Digital Sensor Kariasa (SenDiKa 1.0) was constructed with dimensions of approximately $15 \times 9 \times 4$ cm. The device integrated a 1200 nm infrared sensor and receiver, mounted within a modified KY-039 module, connected to an Arduino UNO microcontroller. The device was powered by a 12V 1.2A adapter and equipped with a 2.4-inch LCD screen for immediate display of results. The interface presented outputs for blood pressure, blood glucose, and cholesterol in user-friendly categories (normal or high).

The system operated automatically when connected to power, requiring only the placement of a finger over the sensor. Raw signals were processed in real time, adjusted by the pre-determined zero offset value of 849, and interpreted through calibration equations embedded in the Arduino sketch.

Block diagram of the SenDiKa 1.0 system.

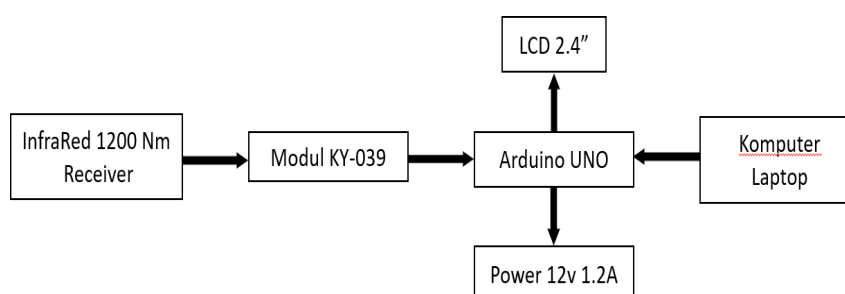


Figure 1. Schematic Diagram of SenDiKa 1.0

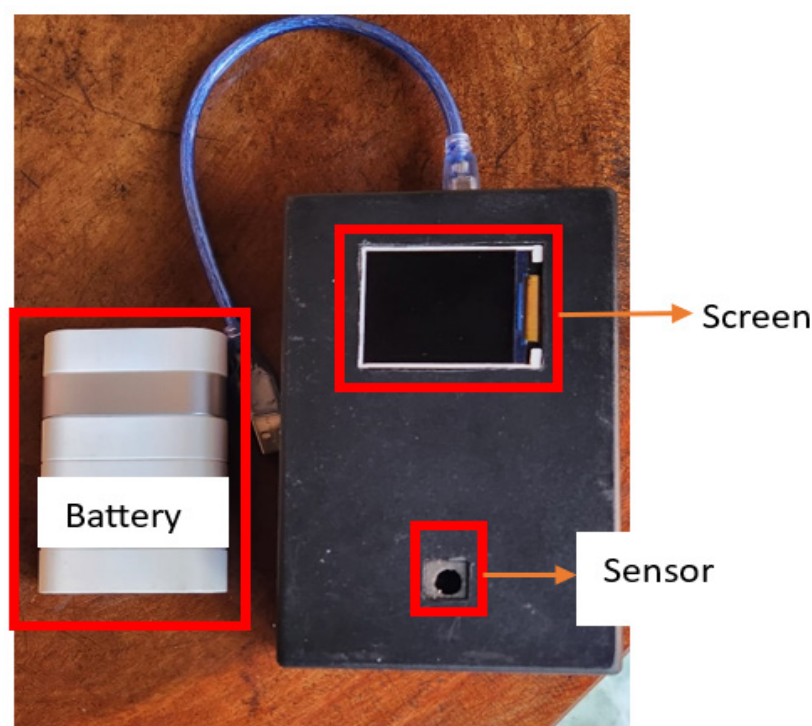


Figure 2. Sendika V1.0

Calibration Outcomes

First Calibration Phase

During the first phase (October–November 2019), 27 paired measurements were performed comparing SenDiKa 1.0 with invasive reference methods. Initial regression analyses demonstrated promising correlation between infrared readings and reference values. For blood glucose, a linear model with a coefficient of determination (R^2) = 0,8664 was obtained, serving as the preliminary predictive equation.

Second Calibration Phase

In the second phase (December 2019), 43 additional participants were enrolled, resulting in an expanded dataset of 70 observations. Data filtering was applied to reduce variability and noise. The regression coefficients derived from calibration were as follows:

- Blood glucose: $a = 0,89$, $b = 20,94$ ($R^2 = 0,9455$)
- Cholesterol: $a = 3,33$, $b = -278,33$ ($R^2 = 1$)
- Systolic BP: $a = 1,79$, $b = -129,14$ ($R^2 = 0,9984$)
- Diastolic BP: $a = 0,4868$, $b = 25,28$ ($R^2 = 0,5564$)

These parameters were uploaded to the Arduino sketch for real-time computation.

Validation of Sensitivity and Specificity

A validation study involving 264 paired measurements compared SenDiKa 1.0 outputs with invasive reference methods. Validation was performed against standard clinical reference devices: a OneTouch Select Plus® glucometer (LifeScan, USA) for blood glucose, a Mission® Cholesterol Analyzer (ACON Laboratories, USA) for total cholesterol, and an Omron HEM-7120® digital sphygmomanometer (Omron Healthcare, Japan) for blood pressure. All reference devices were factory-calibrated and verified prior to use.

Table 1. Sensitivity and Specificity of SenDiKa 1.0 Compared with Invasive Reference Devices			
Parameter	Sensitivity (%)	Specificity (%)	n (measurements)
Blood Pressure	94,5	72,7	264
Blood Glucose	96,3	79,4	264
Cholesterol	64,5	89,4	264

Device Performance and Usability

SenDiKa 1.0 was stable during repeated use and provided results within seconds of finger placement. The LCD display enabled immediate interpretation without the need for external computers. Portability was ensured by the compact design and reliance on standard power sources. Participants reported that the device was simple to use and more comfortable compared to conventional invasive methods.

Table 2. Zero Offset and Stepwise Calibration Models Embedded in SenDiKa 1.0					
Component / Parameter	Phase / Version	n (obs)	Model (form)	R^2	Notes
Sensor baseline	Zero offset	—	—	—	Baseline Analog Read = 849
Blood glucose	Calibration V1 (Oct–Nov 2019)	27	Linear, $Glu = a \cdot X + b$	0,8664	Initial paired comparison
Blood glucose	Calibration V2 (Dec 2019, pre-filter)	70	Linear, $Glu = a \cdot X + b$	lower	Community dataset added
Blood glucose	Calibration V3 (filtered subset)	11	Linear, $Glu = a \cdot X + b$	improved	Representative cases filtered
Blood glucose	Final equation (embedded)	70	Linear, $Glu = a \cdot X + b$	0,9455	Final model uploaded
Cholesterol	Final equation (embedded)	—	Linear, $Chol = a \cdot X + b$	1	Implemented from paired data
Blood pressure (systolic)	Final equation (embedded)	—	Linear, $Sys = a \cdot X + b$	0,9984	Implemented
Blood pressure (diastolic)	Final equation (embedded)	—	Linear, $Dia = a \cdot X + b$	0,5564	Implemented
Note: abbreviations: X = offset-corrected Analog Read (mean of 20 reads minus 849); n/r = not reported.					

In Calibration Version 3 (V3), 11 representative data points were retained after outlier exclusion using the Z-score criterion ($|z| > 3$) and signal quality assessment based on signal-to-noise ratio ($\text{SNR} > 25 \text{ dB}$). The remaining observations represented the most stable readings across repeated trials, which were used to refine regression parameters and reduce noise-induced variability.

Prototype Development SenDiKa 2.0

The previous version (SenDiKa 1.0) exhibited several limitations. The device showed limited portability due to fragile electrical connections that required frequent adjustment during movement. Moreover, repeated calibration refinements were necessary to stabilize sensor readings. The system was also sensitive to ambient thermal fluctuations, which affected infrared signal stability and accuracy.

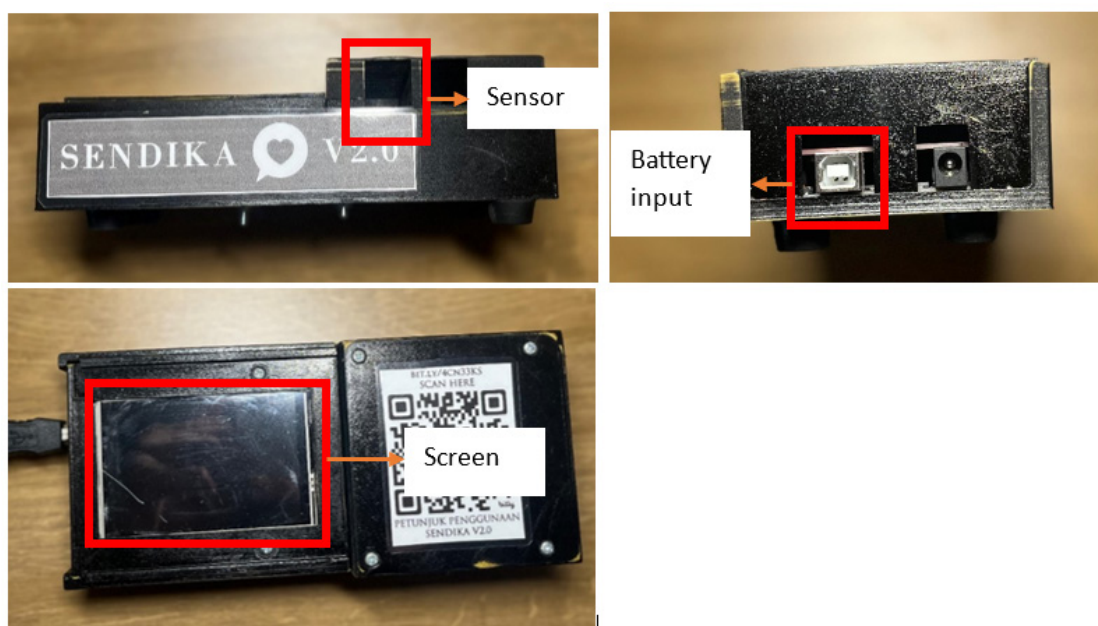


Figure 3. SenDiKa V2.0

Calibration Outcomes

During the first evaluation phase (July 2024-June 2025), SenDiKa 2.0 demonstrated improved mechanical stability and could be transported without disconnection issues. However, ergonomic limitations were identified—the finger chamber was too narrow for some participants, and variations in fingertip curvature and surface texture led to inconsistent optical readings. Out of 229 data entries, 96 met the validation criteria and were retained for analysis. Statistical calibration was deferred until a sufficient number of participants could be recruited to ensure model robustness.

DISCUSSION

The present study describes the development and validation of the Digital Sensor Kariasa (SenDiKa 1.0) and the initial testing of SenDiKa 2.0, both non-invasive prototypes designed to simultaneously measure blood pressure, blood glucose, and cholesterol. The results demonstrated that SenDiKa 1.0 achieved high sensitivity and specificity for blood pressure and glucose, while cholesterol measurement showed moderate sensitivity but high specificity. These findings align with previous research suggesting that infrared spectroscopy and photoplethysmography can provide reliable non-invasive estimations of cardiovascular and metabolic parameters, although challenges remain in extending these techniques to biochemical markers such as cholesterol.^(11,12)

When compared with earlier studies, SenDiKa 1.0's glucose performance, with an R^2 value of 0.9455, is comparable to or higher than that achieved by many non-invasive glucose monitoring prototypes described in the literature.⁽¹³⁾ Previous investigations using near-infrared spectroscopy or saliva-based biosensors often reported inconsistent results due to variability in individual physiology and calibration difficulties.⁽¹⁴⁾ The relatively strong correlation achieved by SenDiKa suggests that the structured calibration process and the inclusion of both laboratory and community-based participants enhanced predictive accuracy and external validity. Similarly, the high sensitivity of SenDiKa 1.0 for blood pressure measurement demonstrates that infrared-based methods can serve as practical alternatives or complements to cuff-based sphygmomanometers, confirming theoretical models of photoplethysmography which emphasize the detection of pulsatile blood flow as a basis for estimating vascular pressures.⁽¹⁵⁾

Cholesterol monitoring, however, continues to represent a major challenge in non-invasive sensing. Prior studies have highlighted the difficulty of distinguishing lipid-related absorption spectra from other biological signals,^(16,17) which explains the moderate sensitivity observed in this study. Nonetheless, the high specificity achieved indicates that positive detections of elevated cholesterol using SenDiKa are likely to be accurate, a result that is consistent with earlier theoretical expectations that specificity is generally easier to attain than sensitivity in optical lipid sensing.⁽¹⁸⁾ The findings suggest that more extensive calibration datasets and advanced computational methods such as machine learning may be necessary to improve cholesterol detection in future iterations.

The development of SenDiKa 2.0 attempted to overcome limitations of the first version by improving portability and reducing sensitivity to movement. These modifications are consistent with prior research emphasizing the importance of ergonomic and user-centered design in medical device development.⁽¹⁹⁾ However, the emergence of new challenges, such as variability in finger placement and difficulty accommodating different finger sizes, limited the number of validated measurements and prevented robust calibration outcomes. This reflects a common theme in non-invasive device innovation: technical refinements can address one set of limitations while introducing new usability or calibration issues that require iterative solutions.

Taken together, the findings indicate that SenDiKa prototypes advance non-invasive health monitoring beyond the scope of previous devices by integrating three critical parameters—blood pressure, blood glucose, and cholesterol—into a single portable system. While earlier devices generally focused on one parameter, SenDiKa addresses the pressing clinical need for simultaneous and user-friendly monitoring of multiple stroke risk factors. This novelty underscores the potential of SenDiKa to support preventive strategies, particularly in community and home settings where access to laboratory diagnostics is limited. Although cholesterol measurement still requires refinement, the feasibility demonstrated in this study highlights the promise of SenDiKa as an innovative step forward in non-invasive health technology.

Strengths and Limitations

The systematic development process of SenDiKa 1.0, involving sensor calibration and validation against invasive standards, is a major strength. The prototypes are compact, portable, and user-friendly, making them suitable for low-resource settings. However, limitations include limited sample size, environmental influences on sensor accuracy, and challenges in cholesterol detection.

SenDiKa 2.0's limited calibration results further illustrate the need for larger and more representative datasets to enhance the reliability and generalizability of the findings. Several limitations must also be acknowledged. Although calibration achieved high accuracy for glucose and blood pressure, cholesterol measurement requires additional refinement and validation with a larger sample size. Moreover, environmental factors such as skin pigmentation, peripheral perfusion, and ambient light may influence infrared sensor readings despite efforts to minimize interference. The relatively small participant pool limits the robustness of statistical analysis, indicating that larger-scale validation is necessary before clinical implementation. Finally, the prototype currently provides categorical outputs (normal or high), which simplifies interpretation for users but may reduce clinical precision compared to continuous numerical values.^(20,21,22)

Implications for Practice and Future Research

Future research should expand calibration databases—especially for cholesterol—integrate machine learning algorithms to improve prediction accuracy, and optimize ergonomic design to fit a wider range of users. Moreover, incorporating features such as wireless connectivity and data storage could enhance clinical integration and usability in community health settings.

CONCLUSIONS

Overall, SenDiKa 1.0 demonstrated promising performance for non-invasive, simultaneous monitoring of blood pressure and glucose, with cholesterol requiring further refinement. SenDiKa 2.0 addressed portability challenges but highlighted new ergonomic and calibration limitations. Continued iterative development and validation are essential to fully realize the potential of SenDiKa as a tool for accessible, non-invasive, and multi-parameter health monitoring.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest”.

AUTHORSHIP CONTRIBUTION

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Formal analysis: I Made Kariasa, Raldi Artono Koestoer, I Gede Juanamasta.

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