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Research Article

Development of an Experimental Platform for Evaluating and Calibrating Gas Sensors via Reference Sensor Technique

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Abstract:

Establishing a test bench for gas sensor characterization is essential to ensure that the developed sensors are efficient, reliable, and suitable for their intended application, while also promoting technological advancements in gas detection. This bench primarily aims to evaluate and analyse sensor performance under controlled conditions. The main objectives include measuring sensitivity, selectivity, response time, and stability when exposed to varying concentrations of target gases, which is crucial for determining their effectiveness in real-world conditions. This work aims to summarize the main achievements in designing and developing an experimental laboratory bench, controlled and managed by an Arduino Uno acquisition module. This gas sensor characterization bench facilitates sensor calibration and the determination of an unknown gas sensor's characteristics based on those of a well-defined sensor.

1.Introduction

Gas sensors play a pivotal role in various sectors by enhancing safety and enabling environmental monitoring. In the industrial sector, gas sensors detect hazardous gas leaks, ensuring the safety of personnel and infrastructure. In residential and commercial buildings, they prevent accidents involving carbon monoxide or natural gas. In healthcare, these sensors analyse exhaled air to detect gaseous biomarkers indicative of certain diseases. In environmental monitoring, gas sensors measure air pollution levels and assist in air quality management [1]. Given their critical functions, it is essential to thoroughly evaluate their performance to ensure reliable operation in real-world conditions [2]. Consequently, designing and implementing specialized test benches for gas sensor characterization is a fundamental requirement.

Characterizing gas sensors involves evaluating their performance by determining several fundamental properties. Sensitivity refers to the sensor's ability to detect low gas concentrations, while response time is the duration needed for the sensor to reach a stable output after exposure to a gas. Selectivity is the capacity of the sensor to differentiate the target gas from other gases, and stability denotes the consistency of the sensor's performance over extended periods. Finally, detection limit represents the lowest concentration of gas that the sensor can reliably detect. Several methods are commonly employed to characterize gas sensors [3-4]. The static method involves exposing the sensor to fixed gas concentrations to evaluate its equilibrium response. In contrast, the dynamic method uses varying gas concentrations to measure the transient response and recovery time. Thermal characterization examines how temperature changes affect sensor sensitivity, while gas cycling alternates the sensor's exposure to different gases to assess selectivity and repeatability. These characterization methods enable a comprehensive analysis of sensor performance, providing insights necessary for optimization and application-specific design. These test benches allow precise analysis of parameters like sensitivity, selectivity, response time, and stability by simulating diverse operational conditions. They provide a controlled environment, optimizing sensor calibration and performance [5]. Automated systems, using acquisition modules such as Arduino Uno, enhance accuracy and reproducibility by managing tests efficiently. Although gas sensor characterization using resistance measurement is well-established [6], this work presents a new automated experimental setup to achieve the following objectives: reducing operator intervention and data extraction time to improve efficiency as well as automating data recording in formats compatible with standard software such as Excel, with an intuitive user interface. The proposed system, controlled by an Arduino Uno acquisition module, facilitates both calibration and characterization of unknown sensors through comparisons with reference sensors. The ultimate goal is to design, construct, and validate a test bench that enhances efficiency, automation, and ease of use, contributing to the development of more precise and application-specific gas sensing technologies. depth and to elaborate the meaning of results.

2.System Architecture: Overview:

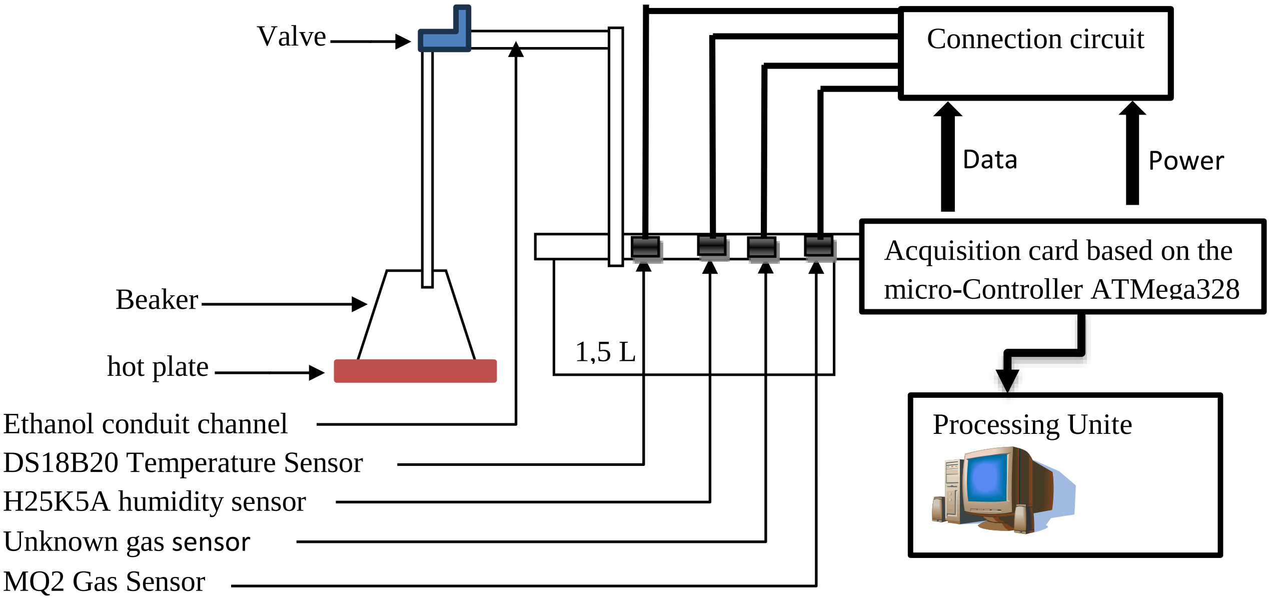
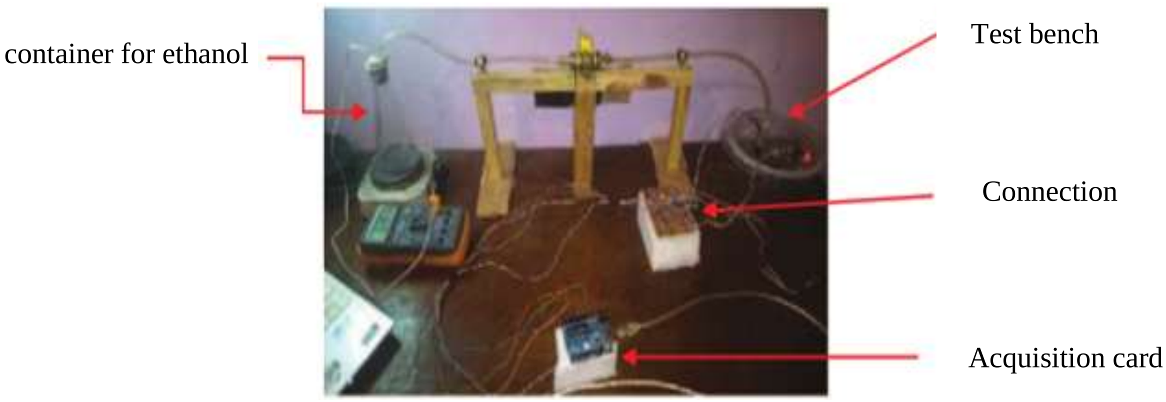


Figure1. *Overall schema of all parts of the experimental platform.*



Figur2. *Actual photo of the experimental device.*

2.1. Manage different sensors using arduino uno board :

The different sensors are connected to the Arduino -Uno acquisition board shown below Fig3, and their 5-volt supply voltage is provided by the same boardjn

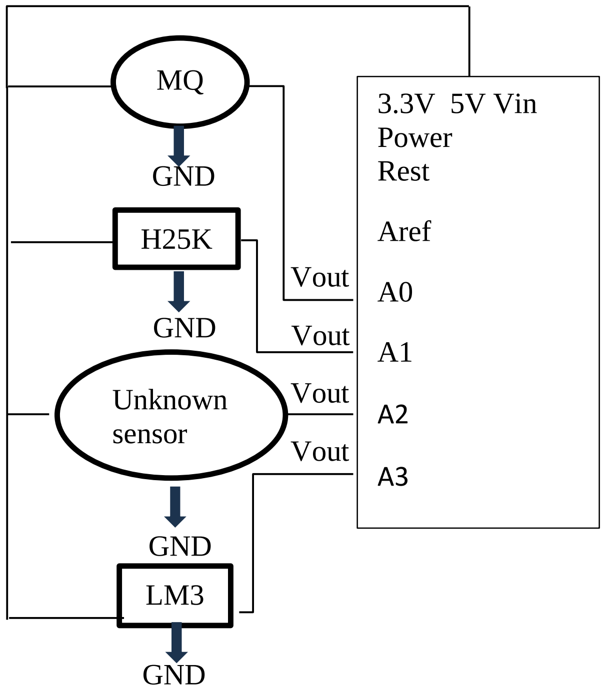
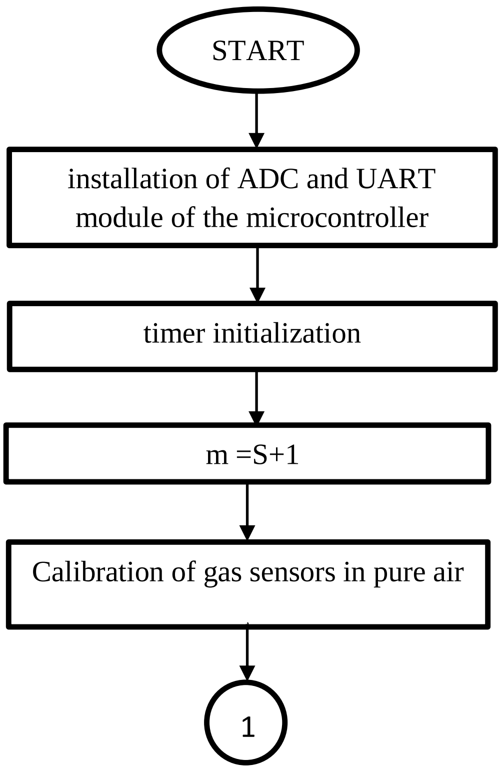


***Figure 3**. Connecting different sensors to the Arduino-Uno acquisition board.*



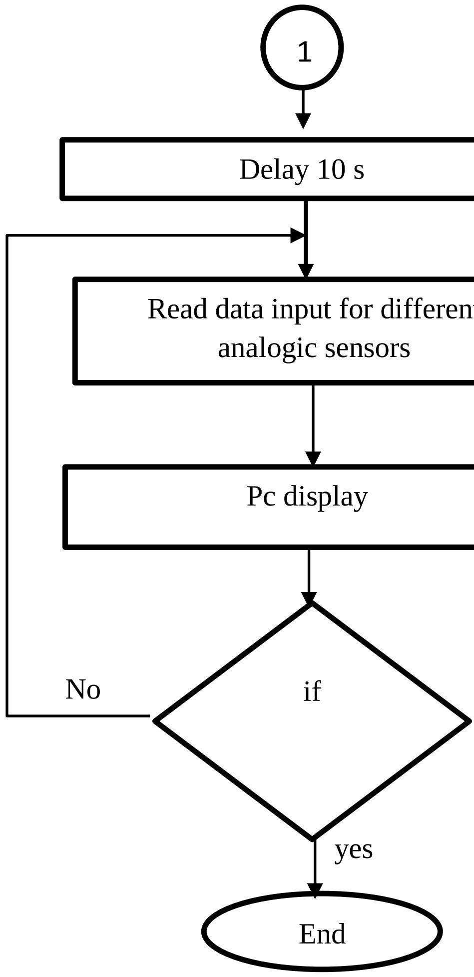


***Figure 4.** Flowchart of the different stages of the data acquisition process.*

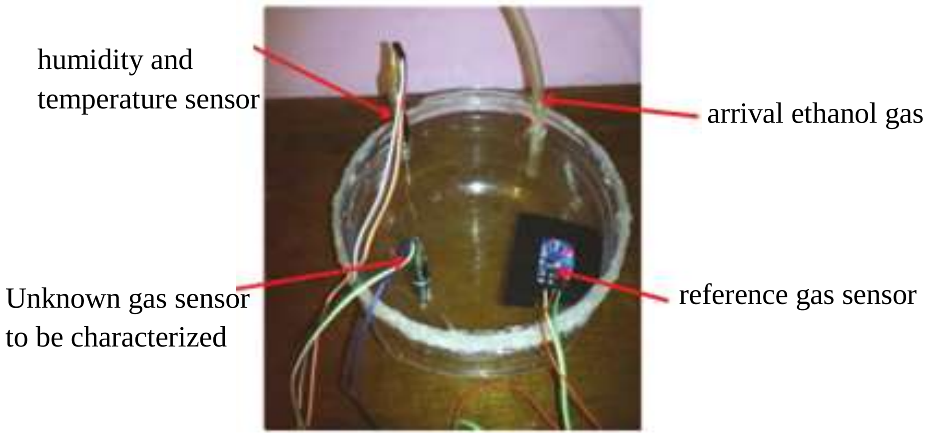


***Figure.5**. Photo Showing the layout of the different sensors with the arrival of ethanol gas in the room*

3. Characterization of an Unknown Gas Sensor :

The objective of this experiment is to characterize an unknown gas sensor using a well-established ethanol gas sensor, the MQ2, as a reference. The characterization process aims to determine the ethanol gas concentration in a controlled environment. In the experimental setup, 10 ml of liquid ethanol is placed in a beaker and heated on a hot plate to facilitate its evaporation into the gaseous phase. The characterization is conducted under ambient pressure, at a room temperature of 23 °C, and normal humidity levels. The air sensitivity resistances (Ro) of both sensors are measured: R_{01}=9.89 kΩ for the MQ2 sensor, and R_{02}=22 kΩ for the unknown sensor.All measurement results are shown in the table 1. The concentrations obtained for different gas intakes are determined using the projection method based on the sensitivity ratio values (R_{S1}/R_{01}) of the reference MQ2 gas sensor.In the glass chamber and for each ethanol intake, the following parameters are determined:

- The output voltage of the standard gas sensor MQ2: V_{RL1} (mV)
- The output voltage of the unknown gas sensor : V_{RL2} (mV)
- Resistance sensitivity of the MQ2 sensor in the presence of ethanol: R_{S1} (KΩ)
- Resistance sensitivity of the unknown sensor in the presence of ethanol: R_{S2} (KΩ).

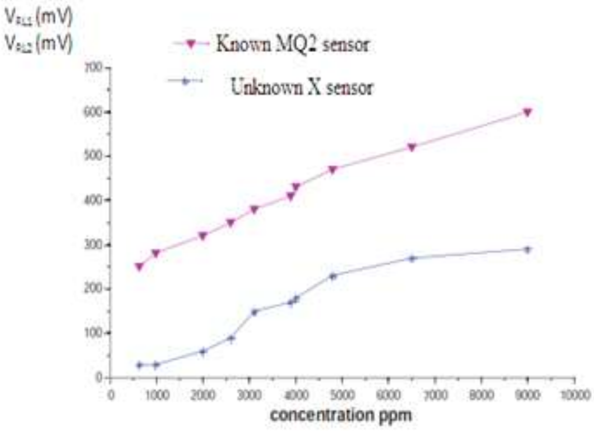


Figure.6. *Output voltage of two sensors as a function of ethanol gas concentration*

Table.1. *Data readings of two MQ2 and unknown sensors subject to ethanol* gas.

V_{RL1} (mV)	250	280	320	350	380	410	430	470	520	600
V_{RL2} (mV)	30	30	60	90	150	170	180	230	270	290
R_{S1}(KΩ)	19	16.8	14.2	13.28	12.15	11.2	10.6	9.63	8.61	7.33
R_{S2}(KΩ)	165.6	165.6	82.3	54.4	32.3	28.4	26.7	20.7	17.5	16.2
R_{S1}/R_{01}	1.92	17	1.47	1.34	1.22	1.13	1.07	0.97	0.87	0.74
R_{S2}/R_{02}	7.53	7.53	3.74	2.47	1.46	1.3	1.21	0.94	0.79	0.73
Concentration (ppm)	630	990	2000	2600	3100	3900	4000	4800	6500	9000

Table 2. *Summary table of the different data for the two gas sensors With the pure air sensitivity resistances of the sensors R_{01} = 11 kΩ, R_{02} = 25 kΩ and R_L = 1 kΩ .*

VRL1(mV)	**190**	**240**	**260**	**530**	**620**	**635**	**645**	**655**	**649**	**640**	**632**	**627**
VRL2(mV)	**130**	**400**	**511**	**530**	**530**	**551**	**605**	**620**	**595**	**582**	**572**	**560**
Rs1(kΩ)	**25.31**	**19.83**	**18.23**	**8.43**	**7.06**	**6.87**	**16.75**	**6.63**	**6.70**	**6.81**	**6.81**	**6.97**
Rs2(kΩ)	**37.46**	**11.5**	**9.41**	**8.78**	**8.43**	**8.07**	**7.26**	**7.06**	**7.40**	**7.59**	**7.74**	**7.92**
Rs1/R01	**2.30**	**1.80**	**1.65**	**0.76**	**0.64**	**0.62**	**0.61**	**0.60**	**0.60**	**0.61**	**0.62**	**0.63**
Rs2/R02	**1.49**	**0.46**	**0.37**	**0.35**	**0.33**	**0.32**	**0.29**	**0.28**	**0.29**	**0.30**	**0.30**	**0.30**
ppm	**340**	**1150**	**1500**	**7500**	**9750**	**9800**	**9900**	**10000**	**10000**	**9000**	**10000**	**11000**
Temperature °C	**19**	**35**	**46**	**52**	**60**	**65**	**71**	**77**	**81**	**84**	**86**	**88**
V humidity (mV)	**698**	**701**	**715**	**725**	**731**	**736**	**740**	**760**	**768**	**771**	**776**	**780**
RH %	**65**	**65**	**58**	**60**	-	-	-	-	-	-	-	-

3.1.Observation of the Curves :

3.1.1 The curve for the MQ2 sensor (purple triangles) shows a continuous increase in output voltage as the gas concentration rises. This trend is consistent with the typical behavior of an MQ2 sensor, which responds to ethanol by increasing its output voltage proportionally to the concentration.

3.1.2 The curve for the unknown sensor (blue diamonds) also shows a voltage increase with rising concentration, but at a slower rate compared to the MQ2 sensor. This indicates that the unknown sensor has a different (likely lower) sensitivity to ethanol compared to the MQ2 sensor.

3.2.Results Analysis :

3.2.1. Comparative Sensitivity:

The slope of the MQ2 curve is steeper than that of the unknown sensor, indicating that the MQ2 sensor is more sensitive to ethanol concentration variations than the unknown sensor.

3.2.2 Operating Range:

Both sensors seem to operate within a range from 0 to approximately 9000 ppm. However, the response of the unknown sensor appears to stabilize or saturate around 8000-9000 ppm.

3.3. Interpretation :

The difference in response between the two sensors may be due to differences in their sensing materials, the design of their sensitive layer, or variations in their calibration constants.

4. Linearity of Responses:

The MQ2 sensor's response appears more linear over a broad concentration range, while the unknown sensor shows irregularities, potentially indicating non-linearity or saturation at high concentrations [7].One thus obtains among the characteristics of the unknown sensor, her sensitivity as a function of the concentration of ethanol gas, which given by the rapport R_{S2} / R_{02}According to the two curves, it can be observed that the value of the ratio of the internal resistance of the gas sensor decreases linearly with the increase in ethanol gas concentration, which is compensated by an increase in the gas sensor output voltage.

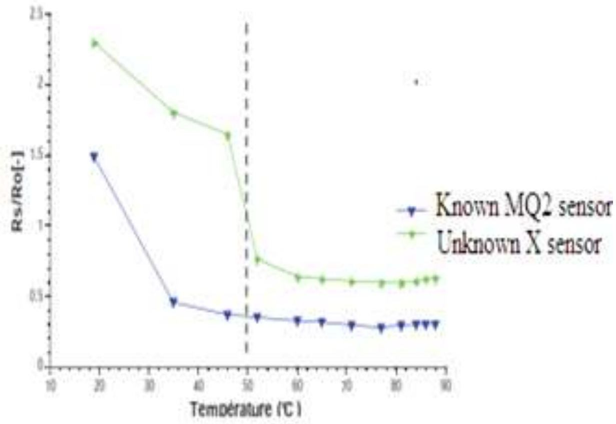


Figure 7. *characteristic of the sensitivity of the two sensors MQ2 and unknown (X) according to the concentration.*

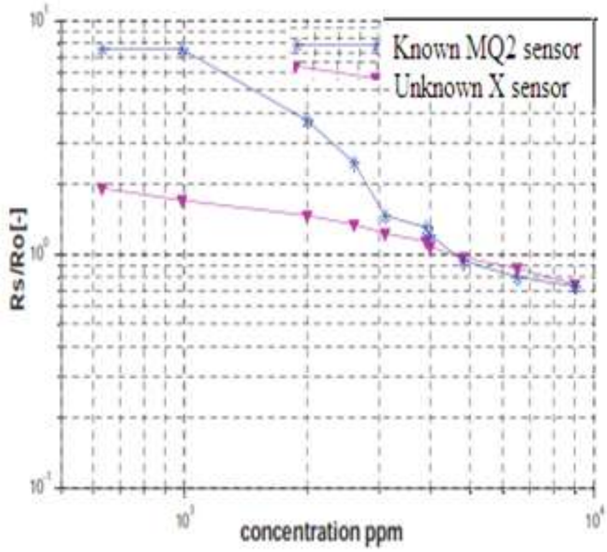


Figure.8. *Sensitivity of both gas sensors MQ2 and unknown (X) as a function of temperature*

5. Influence of temperature and humidity on the sensitivity characteristic of the gas sensor to be characterized :

The following table summarizes the measured values for the various sensors and the derived values for the sensor to be characterized. It should be noted that beyond a temperature of 50°C, the values are unreliable, as the characteristics of the reference gas sensor (MQ2) are provided only within the range of 0°C to 50°C, and the same applies to the unknown gas sensor to be characterized

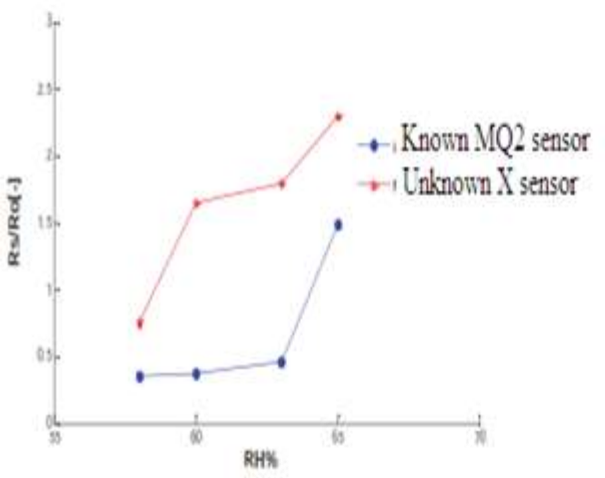


Figure .9. *Sensitivity of both gas sensors MQ2 and unknown (X) as a function of humidity*

6. Conclusion:

In this study, the performance and sensitivity of an unknown gas sensor were characterized by comparison with a well-established reference sensor, the MQ2 ethanol sensor. Through systematic experimentation, key parameters such as output voltage, resistance sensitivity, and ethanol concentration were measured across both sensors in a controlled environment.The results indicate that the MQ2 sensor exhibits a higher sensitivity to ethanol gas concentrations, with a more linear response throughout the measured range. In contrast, the unknown sensor demonstrated a slower increase in output voltage and a less linear response, suggesting lower sensitivity and possible saturation at higher concentrations.Temperature and humidity were also observed to impact the sensitivity characteristics of both sensors. Beyond 50°C, the reliability of both sensors decreased, with significant deviations in their resistance values, highlighting the importance of controlling environmental factors in sensor characterization.Overall, this study provides valuable insights into the comparative behavior of ethanol sensors, and it underscores the need for careful calibration and consideration of environmental variables when deploying gas sensors in practical applications. Future work could focus on improving the sensitivity and linearity of the unknown sensor, as well as extending the testing range for both temperature and humidity conditions

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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