ENHANCED KNOWLEDGE IN SCIENCES AND TECHNOLOGY
e-ISSN: 2773-6385

EKST

Vol. 6 No. 1 (2026) 675-681
https://publisher.uthm.edu.my/periodicals/index.php/ekst

Design and Integration of Electronic Pressure Sensor for Stroke Patient

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DOI: https://doi.org/10.30880/ekst.2026.06.01.075

Article Info

Received: 1 January 2026
Accepted: 15 January 2026
Available online: 9 July 2026

Keywords

Electronic Pressure Sensor, Flex Bend Sensor, Wearable Health Monitoring, Stroke Rehabilitation, Grip Pressure

Abstract

Continuous hand grip pressure monitoring is frequently necessary for stroke rehabilitation to promote healing and avoid overexertion, but current systems are heavy, inflexible, or do not provide real-time feedback. This project aims to develop and integrate a wearable electronic pressure sensor for stroke rehabilitation. To acquire and process data, an Arduino Nano 33 IoT microcontroller was interfaced with a flex bend sensor that was set up in a voltage divider circuit. For real-time monitoring, sensor output was wirelessly transferred to an online spreadsheet and shown locally on a serial liquid crystal display. To determine sensor response, calibration behaviour, and measurement stability, controlled weights and bending angles were applied during experimental testing. Both short and long sensors exhibit near-linear trends appropriate for calibration, and the results demonstrate a distinct and consistent inverse relationship between applied force or bending angle and output voltage. The longer sensor showed greater sensitivity because it has a larger active area. These findings confirm that the proposed system gives reliable and consistent pressure measurements. The prototype developed shows strong potential as a low-cost, non-intrusive tool for monitoring grip pressure during stroke rehabilitation. It also supports future use in wearable health monitoring systems.

1. Introduction

Stroke rehabilitation requires ongoing and reliable monitoring of hand grip pressure. This helps assess muscle recovery and prevent excessive strain during therapy. However, conventional rehabilitation tools and traditional monitoring devices are often bulky and rigid. They also cannot provide real-time quantitative feedback, which limits their effectiveness in wearable applications [1]. Recent advancements in wearable health monitoring systems have allowed for non-invasive measurement of physiological and mechanical signals, such as movement and strain. This supports remote and personalized healthcare solutions [2]. Among various sensing technologies, strain-based sensors have gained a lot of interest. They offer flexibility, are low-cost, and work well for detecting human movement and changes in shape in wearable devices [3].

Flex bend sensors work on a resistive principle, where electrical resistance changes with bending. They have become popular for motion tracking and rehabilitation monitoring due to their high sensitivity and easy integration with microcontrollers [4]. Previous studies show that flex sensors can be integrated with microcontroller-based systems to monitor finger or hand movement in healthcare applications [5]. However, many reported systems struggle with signal noise, calibration stability, and limited real-time data visualization, especially in wearable rehabilitation settings [1]. Additionally, there has been little research on how the physical characteristics of the sensors, such as sensor length, affect sensitivity and measurement performance under controlled loading conditions relevant to stroke rehabilitation. This gap points to the need for a compact, low-cost, wearable pressure sensing system that offers stable signal acquisition, reliable calibration, and real-time wireless data monitoring without complicated circuitry or external amplification.

This study aims to design and integrate an electronic pressure sensing system using a flex bend sensor and an Arduino Nano 33 IoT microcontroller to monitor grip pressure during stroke rehabilitation. The system will have local data display and wireless transmission to Google Sheet platform for real-time monitoring. It will also evaluate sensor performance under different applied forces and bending angles. The rest of this paper is structured as follows: the next section describes the methodology and experimental design, followed by the presentation and discussion of results, and finally the conclusions and recommendations for future work.

2. Methodology

This study used an experimental method to design, integrate, and evaluate a wearable electronic pressure sensing system aimed at stroke rehabilitation. A flex bend sensor served as the main sensing element because it is well-suited for detecting bending and deformation in wearable health monitoring applications [4]. In order to support real-time monitoring capabilities frequently needed in rehabilitation systems, an Arduino Nano 33 IoT microcontroller was chosen for analog data acquisition, signal processing, and wireless data transmission [2]. The experimental procedure included integration of the electronic components, creating software for continuous sensor readings, and calibrating the sensor under controlled bending and loading conditions. Data were collected as analog voltage signals that matched the applied force and bending deformation. This data was then sent wirelessly for remote logging and visualization. The overall method aimed to tackle known issues in wearable strain sensing, such as signal stability, calibration reliability, and ease of integration, which previous studies have highlighted [3].

2.1 System Materials and Components Selection

Because of its resistive operating principle, which enables mechanical bending to be converted into quantifiable electrical signals, the flex bend sensor was selected as the pressure-sensing component [4]. These sensors have been widely reported to be useful for motion and grip tracking in rehabilitation settings due to their flexibility and high sensitivity [3]. The Arduino Nano 33 IoT microcontroller board was used for processing the data due to its compactness and wireless capabilities, which can be very useful for wearable systems implementation [6]. A standard 10 kΩ resistor was utilized for creating a voltage divider circuit along with the sensors, thereby enabling direct reading of the analogue voltage without any external amplification, as has been recommended in previous implementations of wearable sensors [7]. An I2C 1602 serial LCD display module has also been used to enable direct feedback, thus making the overall system usage simpler [8].

Fig. 1 schematic uses an Arduino Nano 33 IoT microcontroller as the main processor. It connects to a 2.2-inch flex bend sensor and an I2C 1602 serial LCD to show data in real time. The flex sensor works with a voltage divider circuit, where it is placed in series with a 10k ohm resistor. The point between the sensor and resistor connects to analog input pin A0, so changes in the sensor's deformation become voltage readings. The sensor and resistor are powered by the 3.3V and GND pin. The LCD uses the I2C protocol, with its SDA and SCL lines connected to pins A4 and A5 for serial communication. The system runs on a 6V DC power supply made from four 1.5V AA batteries connected to the VIN pin. The board's voltage regulator keeps the voltage stable for all parts.

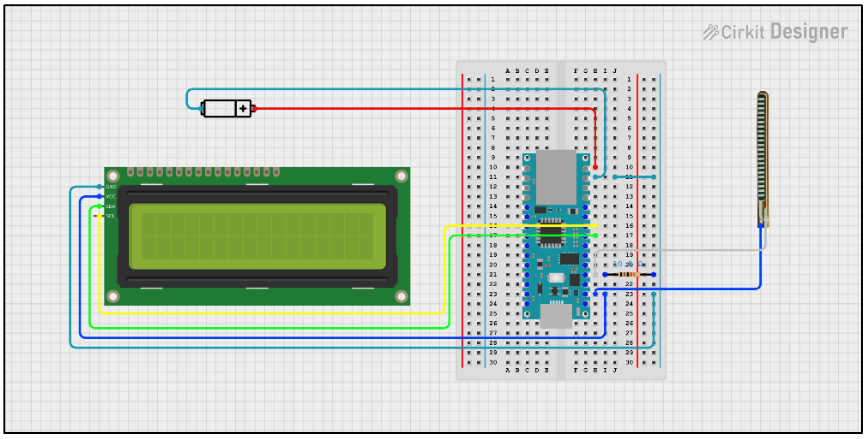

Fig. 1 Schematic Diagram of Electronic Pressure Sensor

2.2 Experimental Setup and System Integration

Fig. 2 shows the experimental setup involved in mounting the electronic components on a solderless breadboard. This allowed for flexible adjustments during development and testing. The flex bend sensor was connected in a voltage divider configuration. The output was linked to an analogue input of the Arduino Nano 33 IoT for continuous signal acquisition. The display module connected using serial communication to keep wiring simple. This is a common method in compact embedded systems [9]. We used the Arduino Integrated Development Environment for embedded programming. This managed tasks like sensor reading, data formatting, and wireless transmission. A system block diagram and flowchart illustrated the signal flow and processing stages. This approach helps improve clarity and reproducibility in experimental sensor-based studies [1].

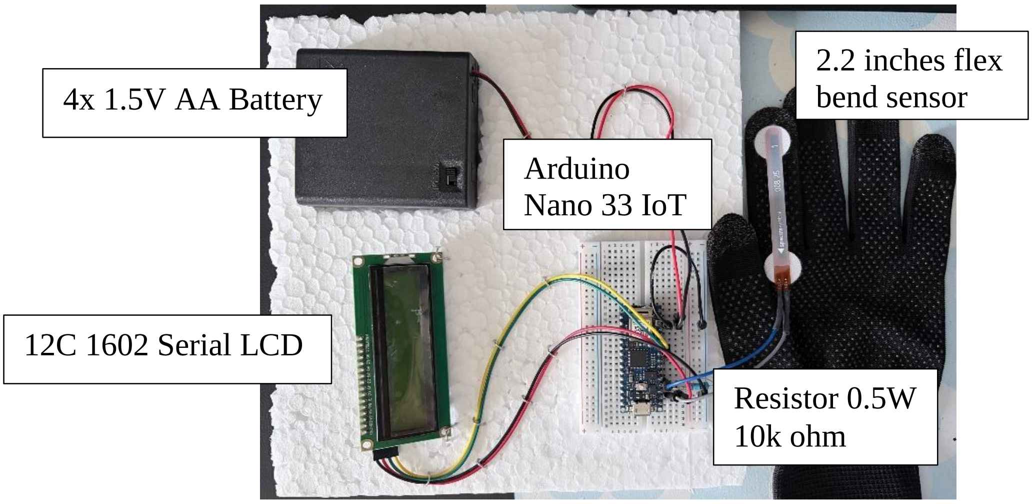

Fig. 2 Full Experimental Setup

Software development was conducted using the Arduino Integrated Development Environment (IDE), which enabled efficient writing, debugging, and uploading of control logic to the microcontroller. The programming logic was designed to continuously sample raw analog signals from the flex sensor through the Arduino Nano 33 IoT's 12-bit analog-to-digital converter (ADC). These raw values were converted to voltage, then to bend percentages and force (N), using calibration constants obtained from experimental data. To maintain data integrity, the code incorporated instructions for initializing I2C communication with the local LCD and establishing a stable handshake with the wireless network prior to entering the main execution loop.

By utilizing the Arduino Nano 33 IoT's integrated Wi-Fi capabilities to interface with the Google Sheets platform, real-time remote data logging was accomplished. The WiFiNINA and ArduinoHttpClient libraries were used by the system to create a secure SSL connection to the Google Apps Script API. The microcontroller processed each sensor reading, formatted the data as a web request, and sent it to a custom Google Apps Script. By programmatically appending the received sensor values such as bending percentage and applied force into specific spreadsheet rows for both short-term visualization and long-term analysis, this script served as a bridge.

2.3 Sensor Calibration and Data Acquisition Procedure

Fig. 3 illustrates the system design of the electronic pressure sensor. Next, calibration was done to ensure a consistent sensor deformation and output voltage correlation before testing the entire system functionality. Bending of the flex bend sensor with step-by-step loading from 0g to 50g, that represent grip pressure experienced during exercise in rehabilitation activities, was done. Fig. 4 illustrates the setup for calibration of 2.2 inches and 4.5 inches flex bend sensor using a known weight. From the calibration, it is shown that as the weight increases, the bend percentage will also increase while the voltage will decrease. To create a conversion factor for useful measurement units, the raw analogue values were mapped to reference positions or known bending angles during calibration.

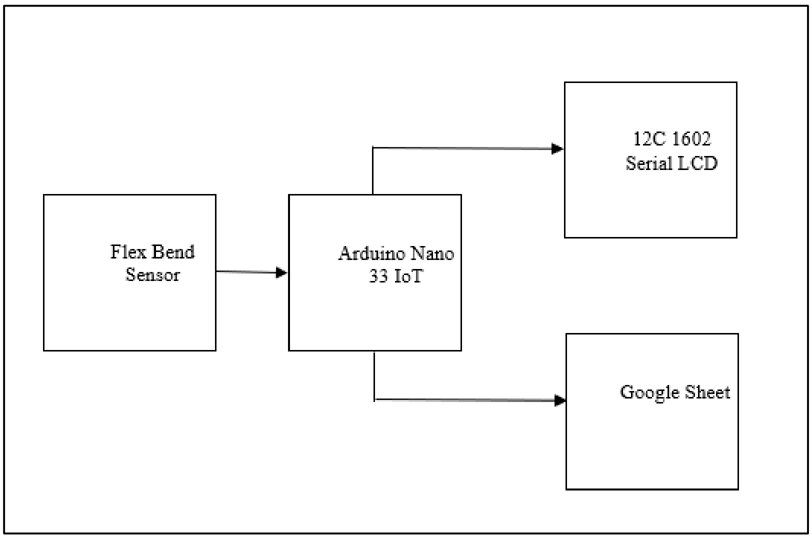

Fig. 3 Block Diagram of Interfacing circuit of electronic strain sensor

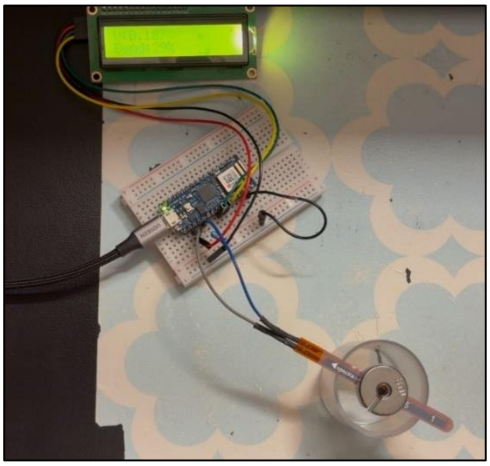

Fig. 4 Calibration of flex bend sensor with 0g to 50g weight

Fig. 5 shows the calibration process using bend angles from 0° to 60°. The sensor's appropriate response to bending changes was confirmed by the observed voltage readings, which averaged between 0.210 to 0.225V in the flat condition of 2.2 inch flex bend sensor, between 0.420 in the flat condition of 4.5 inch flex bend sensor and dropped to about 0.145 to 0.155V during maximum bending of 2.2 inch flex bend sensor, 0.355 to 0.365V during maximum bending of 4.5 inch flex bend sensor. During this process of calibration, the microcontroller collected a few analogue readings to reduce noise and ensure a stable measure of deformation, as has been used in previous strain sensor designs in wearable devices [4]. Direct interpretation of the sensor output would not be possible if the raw voltages were not related to known deformation values by calibration [1].

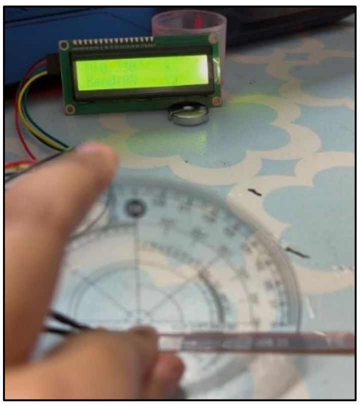

Fig. 5 Calibration of flex bend sensor using 0° to 60° angles

The processed sensor data were then wirelessly transmitted to an online spreadsheet platform for real-time monitoring and storage after acquisition and calibration. Wireless data logging enables remote observation and continuity of monitoring, which are significant benefits from contemporary wearable rehabilitation systems [2]. The approach to the analysis method was from the standpoint of the consistency of the signal, repeatability, and suitability for continuous monitoring, not clinical performance. Graphical portrayals supported the interpretation of sensor behaviour and trends in data, a common approach during the evaluation of wearable pressure and strain sensors [10]. This indeed allows system reliability assessment with a simple, low-cost system architecture suitable for rehabilitation use [3].

3. Results and Discussion

Analysis of the experimental data indicates a strong, consistent, and repeatable relationship between applied force, bending magnitude, and output voltage for both the 2.2-inch and 4.5-inch flex bend sensors. As the applied weight or bending angle increased, the output voltage decreased linearly, consistent with the resistive properties of the flex sensors, where resistance increases with greater bending. The 4.5-inch sensor exhibited higher output voltage and sensitivity compared to the 2.2-inch sensor, attributable to its larger active surface area, which undergoes greater deformation under identical applied weights. The smooth curves observed in the voltage versus weight and voltage versus angle graphs indicate sensor stability and minimal noise, reflecting the effectiveness of the voltage divider configuration and the data acquisition system. Minor limitations were identified, such as the sensors' dependence on the position of applied force and potential output voltage drift during repeated bending cycles. Despite these limitations, the system consistently provided real-time data on applied pressure reliably and efficiently, supporting its potential as a low-cost, effective, and practical solution for wearable stroke rehabilitation applications.

3.1 Sensor Response to Applied Weight

Fig. 6 shows how the sensors respond to added weight. Both the 2.2-inch and 4.5-inch flex bend sensors showed lower output voltage as more weight was applied, which means there is an inverse relationship between force and voltage. This happens because extra weight bends the sensor more, increasing its resistance and lowering the voltage measured across the voltage divider. The 4.5-inch sensor was more sensitive, with a sharper drop in voltage than the shorter sensor, since its longer length bends more under the same load. The almost straight-line trend in the data makes it easier to calibrate the sensors and estimate force reliably, which is useful for tracking low grip pressures during stroke rehabilitation.

To determine the load sensitivity and predictability of the sensors, the relationship between applied weight and output voltage was assessed using linear regression. Compared to the 4.5-inch sensor, which showed a sensitivity slope of -0.820 V/kg, the 2.2-inch sensor showed a sensitivity slope of roughly -1.366 V/kg. This suggests that the shorter sensor produces a greater voltage swing for the same weight increment because it is more sensitive to changes in mass. With fitting coefficients (R^2) greater than 0.998, both sensors demonstrated remarkable linearity. This almost perfect linear correlation indicates a highly uniform resistance change caused by the weight-bearing strain. These findings suggest that wearable rehabilitation technology can use the sensors to measure force or pressure with high precision and low signal noise in addition to movement tracking.

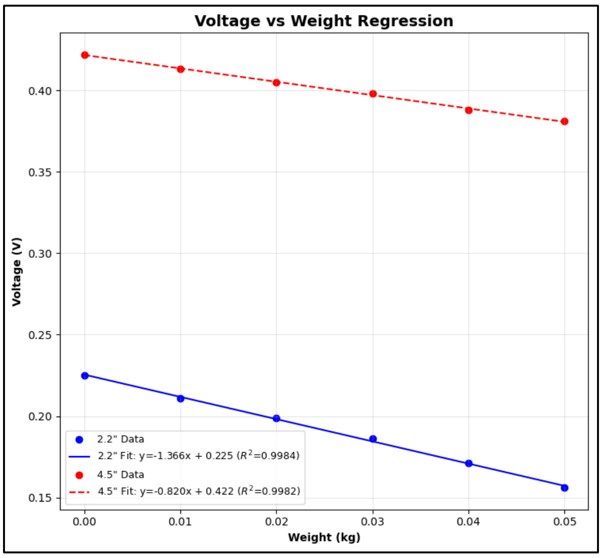

Fig. 6 Graph of Voltage (V) vs Weight (kg) for 2.2 inch and 4.5 inch flex bend sensor

3.2 Effect on Bending Angle on Sensor Output

Fig. 7 shows how the bending angle affects the output voltage of flex bend sensors. For both sensor lengths, the output voltage dropped steadily as the bending angle increased, showing a consistent electrical response to bending. This happens because a larger bend angle increases the sensor's internal resistance, which lowers the voltage measured across the voltage divider. The 2.2-inch sensor had a sharper voltage drop at smaller angles, meaning it is more sensitive to localized bending. In contrast, the 4.5-inch sensor showed a slower voltage change over a wider range of angles. These results show that sensor length affects angular sensitivity and support the use of flex bend sensors for tracking finger and hand movement in wearable rehabilitation devices.

In comparison to the 4.5-inch sensor, which had a slope of -1.011 V/unit, the 2.2-inch sensor showed a higher sensitivity slope of roughly -1.071 V/unit, indicating that it produces a more significant voltage change per degree of bend. Additionally, the fitting coefficients (R^2) for the 2.2-inch and 4.5-inch sensors were determined to be 0.940 and 0.974, respectively. These high R^2 values show a strong linear correlation between the angle and voltage, especially for the longer sensor. For rehabilitation applications, this high degree of linearity is essential because it makes it easier and more accurate to translate electrical signals back into precise joint angles for patient monitoring.

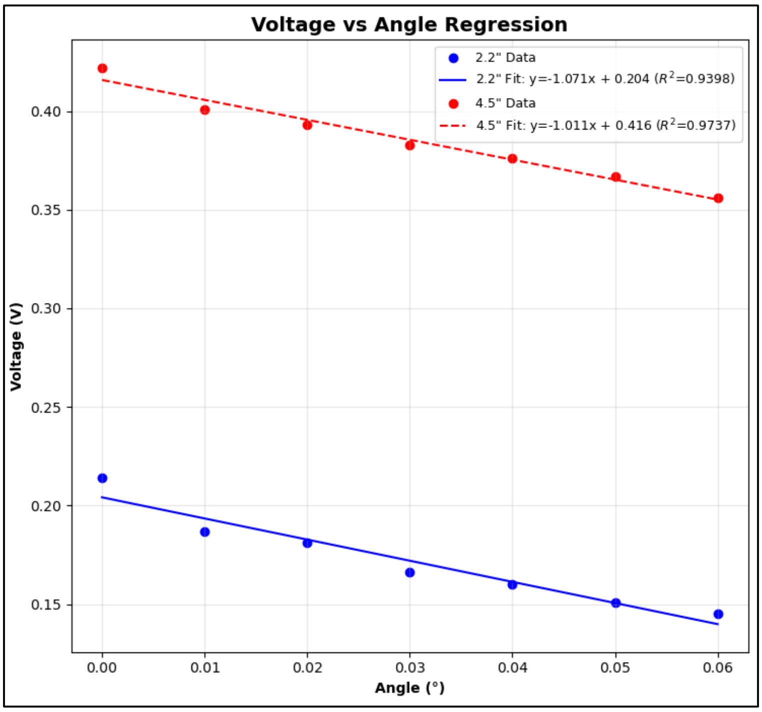

Fig. 7 Graph of Voltage (V) vs Angles (°) for 2.2 inches and 4.5 inches flex bend sensor

3.3 Linearity, Stability and Measurement Trends

Measurement trends from both force-based and angle-based testing demonstrated near-linear and continuous behaviour, which is advantageous for sensor calibration and signal interpretation. Voltage outputs exhibited minimal fluctuation and consistent spacing between data points, indicating strong repeatability and stable signal acquisition. This linearity facilitates the conversion of voltage signals into quantifiable physical parameters, such as bend percentage or applied force, which is critical for real-time wearable monitoring. The consistent trends observed across multiple tests indicate that the voltage divider configuration and data processing approach minimized noise, thereby supporting reliable continuous measurement in rehabilitation applications.

The high degree of linearity seen in the sensor's calibration curves provides additional evidence for the accuracy of these measurement trends. According to experimental data, there was a clear inverse relationship between mechanical input and electrical output for both the 2.2-inch and 4.5-inch sensors. When the applied load reached 0.05 kg, the output voltage dropped by about 0.069 V and 0.041 V, respectively. This steady behaviour implies that the sensitivity of the system stays constant throughout the tested range, enabling accurate conversion of voltage to force (N) or bending percentage (%). Additionally, accurate real-time feedback during repetitive stroke rehabilitation exercises depends on the recorded values being repeatable and resistant to external noise, which is ensured by the stability of the signal acquisition process, aided by appropriate grounding and the 10k ohm voltage divider configuration.

4. Conclusion

By designing and integrating a wearable electronic pressure sensor system for stroke rehabilitation, this study effectively met its three main goals. Initially, an Arduino Nano 33 IoT, an I2C 1602 serial LCD, and a flex bend sensor were used to create an electronic strain sensor system. Second, real-time wireless pressure data display via Wi-Fi was made possible by the system's successful integration with the Google Sheets platform. Lastly, a clear and consistent inverse relationship between mechanical input and sensor output voltage was verified by reliability analysis of the system. For both the 2.2-inch and 4.5-inch sensors, quantitative results showed near-linear calibration behaviour. The output voltage for the 2.2-inch and 4.5-inch sensors dropped by roughly 0.069 V and 0.041 V, respectively, under applied loads of up to 0.05 kg. Because of its larger active sensing area and strain distribution, the longer 4.5-inch sensor showed a larger overall voltage response. These results confirm that the inexpensive, portable prototype overcomes the heavy and inflexible constraints of conventional rehabilitation devices by offering dependable real-time grip pressure monitoring. In order to assess performance during dynamic movement, future research should concentrate on improving the system's long-term robustness and performing clinical studies with human subjects.

Acknowledgement

The author(s) appreciate the Government of Malaysia and Universiti Tun Hussein Onn Malaysia for funding this research project through the UTHM TIER1 Grant (Q417).

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design, data collection, analysis and interpretation of results, draft manuscript preparation****: Nur Elmira Zalia Zulhibabullah, Ahmad Hadi Ali. All authors reviewed the results and approved the final version of the manuscript.*

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