# DESIGN AND DEVELOPMENT OF AN AIRWAY CLEARANCE DEVICE (ACAPELLA) WITH BIOFEEDBACK

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**Abstract**

Clearing the airways is crucial for improving lung function and can be achieved by physical or mechanical methods. The Acapella device is commonly used to clear the airways, by combining oscillations with positive expiratory pressure to reduce mucus adhesion and airway collapsibility, resulting in clear airways. However, without feedback, the optimum therapy cannot be achieved. In this paper, we aim to integrate biofeedback into the Acapella device to enhance its efficacy. We added flow and pressure sensors and a power source to the apparatus to allow for precise measurement and effective signal processing. The graphical user interface displays pressure and mass flow over time, allowing users to monitor and evaluate their exhaled air properties. Our team successfully developed this prototype without altering the device's fundamental principles. The live graphic serves as biofeedback for the patient, with a red zone indicating underperformance or being too high and a green zone representing the accepted performance range. Our innovative device is user-friendly and transparent and delivers optimal therapy at the point of care. This motivates patients to perform better and achieve effective treatment outcomes.

**Keywords:** Acapella, Biofeedback, Airway Clearance Devices with Biofeedback, Physiotherapy.

## INTRODUCTION

It is undisputed that any expertise in physiotherapy practice must be based on a solid evidence base. Respiratory physiotherapy with evidence-based therapeutic devices is the need of the hour. The biggest challenge in delivering respiratory therapy is the patient's dependence on verbal commands and instructions from the caregiver. Lack of motivation to adhere to treatment is the main reason limiting patients' active participation in respiratory physiotherapy [1], following and processing instructions are very subjective. Therefore, the device must be reliable and able to assess airway clearance objectively. In this Paper, we aimed to modify an existing airway clearance device (Acapella) with visual biofeedback to improve efficacy of treatment and ease of use.

Acapella device is most used to support sputum clearance. This device generates a continuous oscillating pressure as the patient exhales through it. The characteristics of the generated pressure, such as producing an average pressure of more than 10 cm H2O and matching the oscillation frequency to the resonant frequency of the respiratory system compared to the frequency of ciliary movement, are crucial for the effective practical use of the Acapella [3]. The Acapella device generates sufficient oscillation frequencies (around 13 Hz) that fall within the range of ciliary motion and respiratory system resonance frequency in patients with lung disease. In addition, the mean pressure measurements generated by this device are most likely high enough to keep the alveoli open during expiration [4,5].

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It has certain limitations; limited flexibility in technique and user-dependent performance may compromise the device's effectiveness in achieving optimal airway clearance. Users require adequate training and guidance to understand and perform the method correctly. The device also lacks personalized feedback without measuring relevant parameters related to the user's condition or progress. Personalized feedback could provide tailored guidance and optimize the effectiveness of the therapy.

Visual feedback for patients performing the manoeuvre with the required pressure and frequency to achieve the desired output. Too low and too high results can be useless for patients. Researchers have also found that pressures above 20 cm H2O are not recommended therapeutically as they pose a risk to the patient [4,6].

The characterization and illustration of the Acapella device can be seen in Figure 1, with frequencies varying from 8.5 to 21 Hz. This also corresponds to the proposed range of ciliary movements and includes the ciliary beat frequencies, which are between 12 and 15 Hz and thus facilitate coughing [7,8].

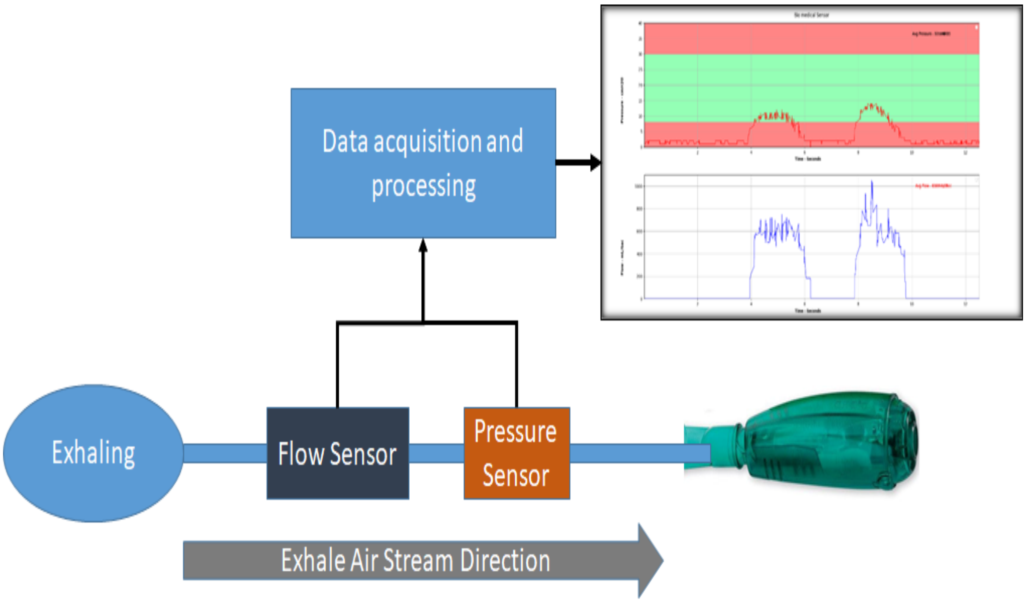


**Figure 1: Flow chart**

## Biofeedback technology

Biofeedback is a potential tool. With the skills one learns from the information provided by a biofeedback device, one can train oneself to recognize one's abilities using biofeedback. As an intervention method for health and well-being, biofeedback exceeds expectations in treating a wide range of conditions such as breathing disorders, cardiovascular disease, neuromuscular disorders, hypertension, anxiety, etc. In most cases, biofeedback has been shown to produce significant positive results [9,10]

Medical devices using biofeedback are top-rated in medicine and biomedical engineering. A biofeedback system connected to the therapeutic device makes the person more aware of their physiological performance and functions [11]. Biofeedback-assisted breathing training would facilitate proper breathing patterns, improve gas exchange, improve ventilation and perfusion, reduce respiratory rate and dyspnoea, improve respiratory function, and minimize sympathetic nervous system activity by reducing secretions.

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The latest technology in microelectronics and computing has led to advances in various sensors that can monitor the patient's health and performance by providing real-time physiological readings to the patient and clinician. The sensors can provide advanced biofeedback to patients and caregivers to assess improvements [9].

The principal objectives of respiratory therapy are as follows:

(i) Enhancing alveolar ventilation to increase alveolar recruitment.

(ii) Enhancing airway clearance to increase secretion clearance.

(iii) Reducing dyspnoea to decrease laboured breathing.

(iv) Enhancing respiratory muscle strength and endurance by improving the patient's physical capacity and in activities of daily living; and Integrate sensors to monitor biofeedback parameters such as lung capacity, airflow, or respiratory rate. Use signal processing algorithms to analyse the biofeedback data. - Provide real-time visual, auditory, or haptic feedback to help users optimize their airway clearance technique. Ensure the accuracy and reliability of the biofeedback mechanism.

## METHODS

### *System design*

Flow and pressure sensors are connected in series to the acapella device in the proposed system. These sensors operate with a 5.0 V input supply and provide output measurements through voltage with an accuracy of 1.5 mV. The flow sensor utilizes a thermal sensor element to detect the flow rate of the exhaled air, ensuring rapid signal processing and bidirectional measurement with precision. The pressure sensor employed in the system features advanced response technology and can operate within a temperature range of 0 to 50 °C, measuring up to 150 cm H2O.

During the exhalation process, the air flows into the device, which is connected to the flow sensor and pressure sensor as part of the hardware setup. These sensors collect electrical signals (voltage) data and transmit it to a computer through an Arduino interface. The real-time data is captured and displayed on the screen using software developed in Python under an open-source license.

**Hardware Design:** The hardware design involves two sensors: the flow sensor and the pressure sensor, both exhibit high sensitivity with a frequency range above 1000 Hz. The flow sensor is a non-contact sensor that employs a thermal sensor element to accurately detect the gas flow rate and facilitate high-speed signal processing. The piezoresistive silicon pressure sensor is responsible for sensing pressure across the designated full-scale pressure span and temperature range.

These sensors are calibrated and temperature-corrected for sensor offset, sensitivity, temperature effects, and accuracy faults using an onboard application-specific integrated circuit (ASIC). The pressure sensor provides digital output, while the flow sensor provides analog output for pressure and flow measurements. The analog output values for pressure are updated at approximately 1 kHz, while the digital output values are updated at around 2 kHz.

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**Software Design:** The software design of the system involves extracting data from the sensors using Arduino support and importing it into a Python environment. The software components, including the graphical user interfaces (GUI).\ The graphical user interface GUI allows users to interact with the system and visualize the real-time data. Users are prompted to enter the patient's name, age, and ID when the software is executed. Additionally, they need to select the appropriate data input source (COM PORT) for communication with the device.

Once the software is configured correctly, it captures the data from the sensors connected to the hardware setup. The captured data, which includes pressure and mass flow measurements, is then processed and plotted on the GUI against time so users can monitor and analyse the exhaled air parameters in real time.

The system's collection, processing, and visualization of data related to the exhaled air flow and pressure. The hardware components, including the flow sensor and pressure sensor, accurately measure the relevant parameters, while the software components facilitate data acquisition, processing, and display.

## RESULTS

A real-time, actual-time plot of pressure and flow individually. In the pressure plot, an option is provided to highlight the minimum and maximum force by the user. The data starts receiving and plotting as it acknowledges the start of data access from the GUI, and it keeps receiving and planning until the command stops data access. Once the process is stopped, all the data points of time, flow, and pressure values are automatically exported in a CSV file in the pre-defined file name.

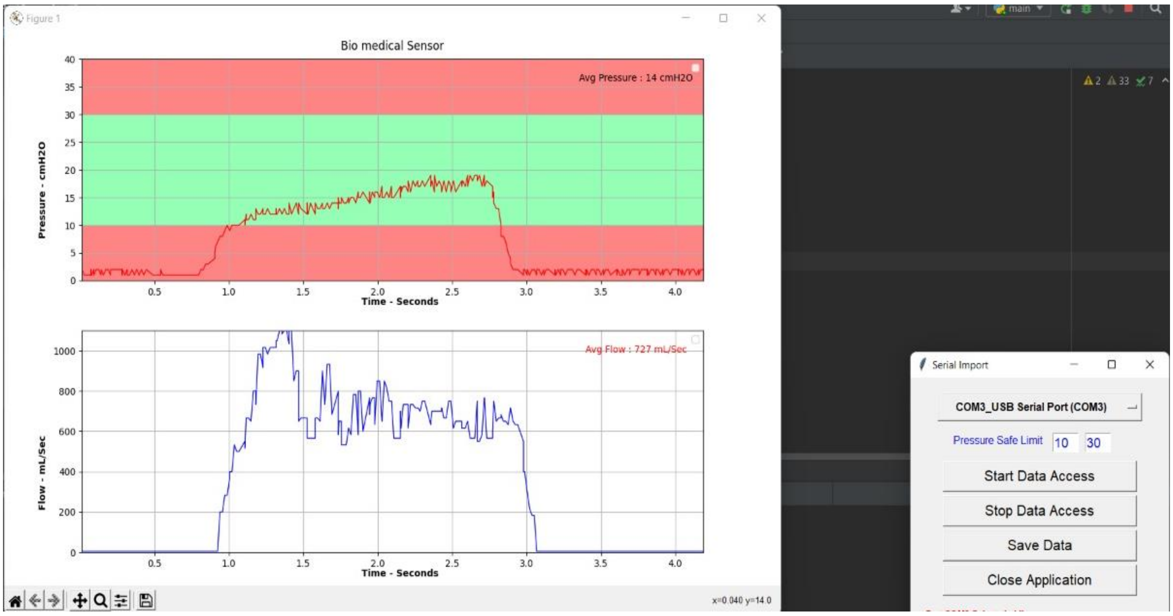


**Figure 2: Biofeedback for the patient**

As shown in Figure 2, the colour blocks in the live graphic serve as biofeedback for the patient. The red colour zone represents an area where the performance is too low or too high. The green colour zone represents the acceptable power range, and the pressure reached in the green zone is the pressure required for the desired effect of the treatment.

The patient is instructed to blow through the device and reach the green zone. The patient repeats this manoeuvre five times in each set. The average recorded back pressure from all five attempts is automatically displayed on the screen. In this way, patients can understand what is expected of them during the exercise in an interactive session. In addition, the patient receives a combination of silicone and piezo spray.

He is motivated to perform better daily, and an effective treatment result is achieved through the combination of silicon and piezo jet. The advanced automated software saves the patient's day by improving pressure and flow measurement. Assuming the patient can achieve the desired treatment effect, in this case, the recovery rate will be faster, undoubtedly improving patients' quality of life with respiratory diseases.

## DISCUSSION

Several researchers have already emphasized the importance of biofeedback in various airway clearance therapies and devices [11]. Various research papers emphasize the importance of patient adherence and motivation when performing chest physiotherapy treatments for an effective outcome.

Technological progress invites researchers to improve therapeutic and diagnostic medical devices continuously. Developing software programs that respond to the needs of patients in video games, virtual reality, etc., is an important step. The development of intelligent methods for storing and using patient information and treatment histories makes it highly convenient for doctors to design individualized, patient-centred treatment programs. In this study, we modified and optimized Acapella by adding external biofeedback to emphasize advanced performance. Manual adjustments take a lot of time and may need to be more accurate. Oscillatory PEP (OPEP) is intended for use in conjunction with a continuous expiratory manoeuvre [4]. A program with high potential has been developed for clinical use. For example, this application could help patients adjust and perform the manoeuvre according to their individual needs and abilities. Patients are instructed to breathe in with a larger tidal volume than is usual in the clinical environment. They are instructed to inhale enough air without filling the lungs, followed by a steady exhalation for at least 4 seconds without going below functional residual capacity.

Therefore, the OPEP manoeuvre differs from the forced exhalation manoeuvre performed during pulmonary function tests. We hypothesize that advanced engineering and state-of-the-art technology in airway clearance devices may improve mucus clearance in patients with lung disease. When the pressure that builds up behind the occlusion is released, there is an increase in acceleration and short bursts of high flows, which increases mucus support and significantly affects accelerated mucus clearance. The greater the pressure build-up, the stronger the subsequent flow surge. Generally, the patient must be aware of the required pressure and flow during treatment. Biofeedback could generate the necessary tension in the lung fields, together with the contribution of the contracted respiratory muscles during exhalation, which can create this pressure.

## CONCLUSION

Our modified device measures and visualizes exhaled air parameters to aid in respiratory treatment and improve patient outcomes. This device is user-friendly and transparent and delivers optimal therapy at the point of care.

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