Telemedicine for the Management of Nasal Obstruction: An Innovative Approach to Remote Monitoring

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***Abstract*—Nasal polyposis and chronic nasal obstruction significantly impact patients' quality of life and require continuous clinical monitoring. Traditional follow-up methods, based on frequent in-person visits, are often inefficient and burdensome for both patients and healthcare systems. This study presents a telemonitoring solution enabling remote assessment of nasal airflow using a customized version of the Spirobank Smart device. Mechanical and software adaptations were implemented to measure Peak Nasal Inspiratory Flow (PNIF) and transmit data in real time to clinicians via a secure digital infrastructure. The system was validated on 30 healthy volunteers by comparing measurements with those from a standard PNIF Meter. Statistical analysis showed no significant difference between the two devices. The proposed solution offers a reliable, accessible, and cost-effective tool for managing chronic nasal conditions remotely, with potential to improve long-term care and patient autonomy.**

***Index Terms*—Telemedicine, Nasal Obstruction, Remote Monitoring, PNIF, Chronic Disease Management**

I. Introduction

The term *nasal obstruction* commonly refers to conditions and injuries that partially or completely block airflow through the nasal cavity, as described in [1]. According to the report, more than 20 million Americans are affected by this condition each year. In the study [2], the authors wrote that epidemiological studies show that the prevalence of CRSwNP (Chronic Rhinosinusitis with Nasal Polyps) varies from 2% to 14%, depending on geographical area and diagnostic criteria. Concerning CRSwNP, the estimated prevalence is approximately 1–5%, again with a variability based on geographical areas. Randomized controlled trials and real-life data suggest that asthma is present in 30–60% of individuals with CRSwNP, while CRSwNP is present in up to 70% of patients with bronchial asthma.

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A. Management of Nasal Obstruction-Chronic Rhinosinusitis

Nasal obstructive diseases, particularly *chronic rhinosinusitis* (CRS), significantly impact patients' quality of life. They are often associated with symptoms such as facial pain, nasal congestion, loss of smell, sneezing, and headache [3].

The diagnosis and treatment of CRS and other nasal obstructive diseases require a multidisciplinary approach, making the clinical pathway both complex and prolonged. In addition to objective evaluations, subjective assessments, such as standardized questionnaires SNOT-22 (Sinonasal Outcome Test) [4] or ACT (Asthma Control Test) [5], are commonly used to gauge disease severity and patient quality of life. However, a significant discrepancy often exists between subjective reports and objective clinical findings. Furthermore, the chronic and recurrent nature of these conditions necessitates frequent outpatient visits. The increasing need for chronic disease management places continuous strain on healthcare infrastructures. In specific cases, such as nasal polyposis, patients require continuous monitoring, long-term pharmacological treatment, and, frequently, repeated surgical interventions due to high recurrence rates. Additionally, in many cases, the referring hospital or clinic is not located near the patient's residence, and limited mobility in certain regions further exacerbates these challenges.

B. Telemedicine

Technological innovation plays a crucial role in this context, offering solutions to improve healthcare efficiency and enhance patient safety. As highlighted in [6], telemedicine has become a key component of healthcare system optimization, enabling remote monitoring and care delivery for patients with chronic diseases. Several recent studies have explored its application in respiratory disorders. For instance, in [7], telemedicine was used for the management of asthma, where patients shared spirometric data and completed standardized questionnaires. The study demonstrated that such systems improve disease monitoring and patient engagement. Similarly, [8] assessed the feasibility and acceptability of a self-

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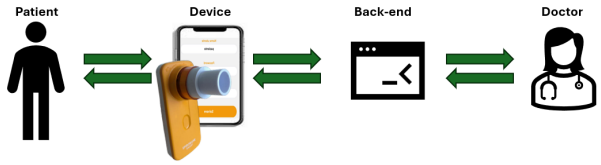

Fig. 1: Telemonitoring system for patients with nasal obstructive disease

management app for asthma, showing that patients were able to detect early signs of worsening symptoms and act according to their treatment plan. Furthermore, during the COVID-19 pandemic, [9] reported the successful implementation of telemedicine in rhinology, highlighting its practicality and effectiveness in ensuring continuous care.

C. Our contribution

In this work, we present a novel telemonitoring system designed for patients with nasal obstructive diseases (Figure 1), with a specific focus on CRS. While the platform was conceived to support a wide range of obstructive conditions, we initially calibrated it for patients with nasal polyposis, a pathology often coexisting with asthma. As a preliminary step, the system was tested on healthy subjects to validate the device's accuracy and usability before its deployment in hospital-based trials on real patients, which will be conducted under medical supervision.

The main contributions of this study can be summarized as follows:

- adaptation of the Spirobank Smart for PNIF testing through mechanical and software modifications;
- implementation of a remote data management system ensuring privacy-preserving collection, aggregation, and visualization;
- definition of a standardized PNIF measurement protocol to guarantee accuracy and repeatability.

The remainder of the paper is structured as follows. Section II outlines the rationale behind the study, providing the foundation that guided the solution's development and the formulation of the research question. Section III presents the entire system, detailing the customization of the medical device, with a focus on the modifications implemented to enhance its multifunctionality and suitability for the study's objectives. Additionally, the data management system and the management of privacy issues are described. This section introduces the measurement protocol, designed to ensure the accuracy and repeatability of the collected data. This section also provides a description of how the experiment was conducted. Section IV presents the results of the statistical analysis conducted on the data. The limitations encountered during the experimentation phase are described in V, and finally, conclusions are presented in Section VI.

II. Background

In this section, we present a high-level overview of the diseases, nasal polyposis and asthma, that guided the design of our telemonitoring solution. Additionally, we introduce the PNIF assessment, a widely used measurement test for evaluating the progression of these conditions, which our system is designed to perform.

A. Chronic rhinosinusitis: Nasal Polyposis

Chronic rhinosinusitis (CRS) is a prevalent chronic inflammatory condition, affecting roughly 10% of the global population [10]. It presents as a heterogeneous disorder marked by persistent inflammation of the upper airways and paranasal sinuses lasting at least 12 weeks, often resulting in a substantial decline in quality of life. CRS encompasses a wide spectrum of clinical manifestations, frequently associated with comorbidities such as asthma, aspirin-exacerbated respiratory disease (AERD), allergic fungal rhinosinusitis, and cystic fibrosis. Traditionally, CRS is classified into two primary phenotypes based on the presence or absence of nasal polyps (NPs): CRS with nasal polyps (CRSwNP) and CRS without nasal polyps (CRSsNP). [11] Nasal polyps are lesions resulting from chronic inflammation of the nasal and paranasal sinus mucosa. While their exact etiology remains unclear, they have been linked to allergy, asthma, infections, cystic fibrosis, and aspirin sensitivity. The primary symptom of nasal polyposis is persistent nasal obstruction, with severity fluctuating depending on the location and size of the polyps [12]. Numerous studies underscore the challenges in identifying patients with nasal polyposis, as many cases remain undiagnosed or are only detected at an advanced stage, delaying appropriate treatment interventions.

B. PNIF Assessment

PNIF assessment assumes that good nasal patency is characterized by low nasal resistance, high nasal cavity volume, and a high peak flow rate. Literature defines a cutoff value of 120 L/min to classify individuals as having normal or impaired nasal airflow. Values below this threshold are typically associated with nasal obstruction due to conditions such as allergic rhinitis, CRS, and nasal polyposis [13]. Studies have demonstrated that PNIF correlates well with subjective nasal obstruction scores and other objective measures such as acoustic rhinometry and rhinomanometry, making it a valuable tool for assessing nasal airflow limitation [14].

PNIF measurements can also be influenced by various factors, including age, gender, body position, and effort applied during the test. Research indicates that PNIF values tend to decrease with aging and are generally higher in men compared to women due to anatomical differences in nasal cavity dimensions [15]. Additionally, certain interventions, such as intranasal corticosteroid therapy or surgical procedures (e.g., functional endoscopic sinus surgery), have been shown to significantly improve PNIF values, reflecting enhanced nasal patency [16].All studies conducted for peak nasal inspiratory flow assessment have utilized the Youlten Peak Nasal Flow Meter (CLEMENT CLARKE INTERNATIONAL), as shown in Figure 2.

Fig. 2: Youlten Peak Nasal Flow Meter (CLEMENT CLARKE INTERNATIONAL)

III. Material and Methods

We develop a modular telemedicine infrastructure adaptable for the remote monitoring of nasal obstructive and chronic diseases, with a case study on nasal polyposis and asthma. The objective is to create a scalable system capable of supporting the long-term follow-up of patients with complex respiratory conditions, often characterized by multiple comorbidities.

A. Spirobank Smart (MIR)

The Spirobank Smart spirometer by MIR (Figure 3a) was originally designed for standard spirometry testing, it features an intuitive and user-friendly interface, making it ideal for personal use. The device serves as a simple yet precise tool for patient telemonitoring and home healthcare, seamlessly integrating with an easy-to-use mobile application. The spirometer connects to a remote system via Bluetooth technology. Once the corresponding application is installed, the device automatically pairs with the remote system, ensuring seamless data transmission. Measurements are performed using a turbine sensor, which operates by detecting interruptions in an infrared beam. For each recorded parameter, the application displays numerical results.

(a) Original Device (b) Customized Device

Fig. 3: Comparison between the original and customized Spirobank Smart spirometer

Spirometer Customization

To ensure the accurate measurement of additional respiratory parameters beyond standard spirometry values, such as the PNIF, mechanical modifications to the device were necessary. Specifically, a disposable anesthesia face mask was employed. To address the technical discrepancy between the mask connector diameter and the turbine housing diameter of the spirometer, a custom adapter was designed and 3D-printed. These adapters provided a secure connection, ensuring precise nasal inspiratory flow measurements while preserving the overall functionality of the device (Figure 3b). The original version of the spirometer enabled the visualization of the flow-volume curve during both exhalation and inspiration, where there are curves for three trials. However, since it was designed based on a traditional spirometry profile, it did not provide the user with the exact numerical value of the inspiratory nasal flow peak. Thanks to the implemented modifications, we were able to automatically extract and display this value within a dedicated section.

B. Data Management System

To facilitate the management of measurement results, a dedicated data transfer mechanism was developed in collaboration with MIR. This mechanism enables a seamless and secure connection between the mobile application and a remote data management system, ensuring real-time data transmission.

The data management system architecture is built on a *RESTful API* framework, designed to ensure high interoperability, scalability, and data security. Healthcare facilities seeking access to the system must establish a dedicated communication interface within their existing information infrastructure. This integration incorporates authentication and access control mechanisms to comply with health data privacy regulations. Patient data are securely stored in a dedicated database while maintaining strong encryption and role-based access control. The infrastructure supports real-time access to patient records, allowing authorized clinicians to retrieve and analyze respiratory measurements instantaneously. To ensure data integrity and confidentiality, strict security protocols, including encrypted communication channels, have been implemented.

To enhance accessibility and usability for both patients and healthcare professionals, two different modes of data access and visualization are available.

- *Mobile Application*: the application, an integral part of the medical device produced by MIR, is provided to customers purchasing the spirometer and serves as the primary interface for displaying respiratory parameters. It has been modified to enable accurate measurement of the PNIF and to ensure patient's privacy.
- *Web Application*: developed to facilitate patient registration, data management, and real-time visualization of respiratory parameters by healthcare providers, the web-based application offers an intuitive dashboard for medical personnel. It allows clinicians to track patient progress over time and analyze trends in PNIF and other parameters measurements.

C. Management of privacy issues

The design of a telemedicine system that relies on third-party applications introduces significant challenges in managing and protecting user privacy, especially during the experimental phase. To address these concerns, several updates were made to the application connected to the spirometer.

Each participant was assigned a unique identifier (ID) and is recognized within the app solely through this pseudonym. Only authorized physicians involved in the study can link this ID back to the actual patient identity. Furthermore, any application fields requiring sensitive personal data, such as full date of birth, were modified. For example, the endpoint now accepts only the year of birth, reducing identifiability while retaining clinical relevance. Special attention was also given to patient login credentials. To avoid the use of personally identifiable email addresses, we implemented a mechanism that generates anonymous email aliases for each participant. A single, centralized patient profile is created and managed

exclusively by the physician responsible for the study. The doctor assigns an alias to each patient, allowing them to access the mobile application, receive notifications or instructions, and participate in the remote monitoring process without revealing their real identity.

Access to the web platform is strictly restricted to authorized healthcare personnel. A secure authentication system based on username and password has been implemented. Upon login, the physician's identity is verified through an API that validates the issued token. Only after successful token validation can the main dashboard be accessed, ensuring an additional layer of protection for patient data.

D. PNIF Measurement Protocol

The measurement of PNIF using the Spirobank Smart required a thorough analysis to establish an appropriate measurement protocol, ensuring accurate detection of the target parameter while maintaining compliance with the spirometer's operational protocols. The mobile application determines the correct execution of the test based on the standard spirometry measurement process. Consequently, a balance had to be found between the device's built-in spirometric protocol and the specific requirements for PNIF measurement. The protocol was validated and drafted with the collaboration of medical personnel, who, after conducting appropriate analyses and observations, approved the following. The test protocol consists of three consecutive measurements, performed at one-minute intervals. This structure is based on literature findings indicating that training effects influence patient performance [17]. Specifically, the first measurement result often differs from the second and third, which tend to be more consistent.

Best practices

Several precautions must be taken into account before performing the PNIF measurement:

- *environmental acclimatization*: the patient should acclimate to the room before testing. Conducting the test in a familiar setting, such as the patient's home, has been shown to reduce stress and enhance patient cooperation;
- *testing posture*: conducted in an upright position, as this optimizes thoracic expansion and maximizes inspiratory muscle efficiency. Poor posture may reduce inspiratory capacity, negatively affecting the results;
- *device setup*: after installing the application and connecting the smartphone to the spirometer, the test can begin;
- *equipment assembly*: the adapter and the face mask must be inserted properly into the spirometer's turbine housing;
- *mask seal*: the face mask must fit perfectly against the patient's face to prevent airflow leaks, as these could compromise the accuracy of the measurements.

Essential steps of PNIF measurements

Each of the three aforementioned PNIF measurements consists of the following three essential steps:

1) *first inspiration*: the patient must inhale as forcefully as possible through the nose. This initial maneuver records the maximum inspiratory nasal airflow capacity. The patient must exert maximum effort to obtain an accurate baseline reference value.
2) *exhalation*: the patient should exhale fully through the mouth. This step ensures a balance between the application's default settings and PNIF detection requirements. Exhalation does not negatively impact PNIF measurement and allows the application to correctly classify the test. Proper exhalation resets the lungs, preparing the patient for the next inspiratory effort.
3) *second inspiration*: the patient must inhale forcefully through the nose once again. This second inspiratory effort serves to validate the initial measurement and ensure test repeatability. Repeating the test allows for the identification of potential variations in measured values, thereby enhancing the reliability of the results.

During the measurement of PNIF, it is essential that the subject keeps their mouth closed during the inspiratory phase to ensure an exclusively nasal airflow and obtain accurate data. While implementing a mechanism to enforce complete mouth closure would be ideal, this is impractical due to the requirement for a second exhalation phase, explicitly requested by the application. Therefore, the subject must pay close attention to keeping their mouth closed during inspiration to prevent data inaccuracies.

E. Subjects

Before deploying the system to patients, the protocol was validated on a cohort of 30 healthy subjects. All participants in the experimental phase received comprehensive training on the correct use of the spirometer and its accompanying mobile application. The initial validation phase was conducted in the University of Rome Tor Vergata, where participants were encouraged to perform the measurements independently, without specialized staff assistance, to simulate a home environment. The sample population used in this phase, summarized in Table I, consists of eight women and twenty-two men, with a mean age of 33.5 years.

Characteristics	**Value**
Gender	Female (8), Male (22)
Mean Age	33.5

TABLE I: Characteristics of the sample population

Each subject in the study underwent three tests with both the PNIF Meter (Clement Clarke) and the Spirobank Smart. The tests with the PNIF Meter were performed first, with one-minute intervals between measurements. After a brief pause, the subjects repeated the procedure with the Spirobank Smart device. All tests were performed in a standing position with attention to the proper fitting of the mask on the face. Prior to the tests, subjects were instructed on the best practices for taking measurements with both devices, and they signed an informed consent form to participate in the study.

For each subject, only the best result was considered. Furthermore, since the two devices used different units of measurement, all results were converted to *L/min* to ensure

uniformity. One sample was excluded from the dataset because significant inconsistencies were found in the measurements.

IV. Statistical Analyses and Results

Statistical analysis was performed on the two data distributions to compare the results and detect any statistically significant differences. The characteristics of the two distributions are summarized in the Table II. An independent samples *t-test* was conducted to assess whether there is a statistically significant difference between the means of two populations, μ_1 and μ_2. The test was performed under the null hypothesis H_0, which assumes no difference between the population means, i.e., $\mu_1 = \mu_2$.

	Spirobank Smart	**PNIF meter**
Mean	111.26	104.33
Median	102.3	100
Standard Deviation	39.84	39.36

TABLE II: Characteristics of the distributions of measurements collected from the two devices

Prior to performing the *t-test*, the ratio between the maximum and minimum standard deviations was calculated to evaluate the homogeneity of variances

$$R = \frac{\max(s_1, s_2)}{\min(s_1, s_2)} \tag{1}$$

An R value close to 1 suggests comparable variances, supporting the applicability of the standard t-test. To verify the suitability of the test, the assumption of normality was assessed using graphical analysis and appropriate statistical tests, as illustrated in Figure 4. The computed R value is approximately 1, confirming the similarity of the two standard deviations.

The estimated t-value was computed as follows

$$t_{estimated} = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{2}$$

where $\bar{x}_i$ and s_i^2 represent the sample mean and sample variance, respectively, of the i-th distribution, and n_i denotes the sample size of the corresponding population. The computed estimated t-value is 0.67. By comparing it with the t-distribution tables, choosing a confidence level of $\alpha = 0.05$ and degrees of freedom equal to $30 + 30 - 2 = 58$, a theoretical t-value of 1.6 is obtained. Since $t_{estimated} = 0.67 < 1.6 = t_{theoretical}$, the null hypothesis H_0 (i.e., no difference between the two groups) cannot be rejected. Therefore, the difference between the two devices' measurements is not statistically significant.

Several graphical representations were used to visualize the comparison between the two distributions:

- the histogram in Figure 4 displays the frequency distribution of measurements obtained using the PNIF Meter (Clement Clarke) and the Spirobank Smart. The two distributions overlap significantly, suggesting that the measurements from the two devices are very similar in terms of central tendencies and variability;
- the boxplot in Figure 5 compares the distribution of the two datasets, with each box representing the interquartile range and the line inside the box indicating the median. Both distributions appear similar in terms of dispersion and central tendency, further reinforcing the conclusion drawn from the t-test;
- the plot of the t-statistic distribution in Figure 6 shows the probability density function of the Student's t-distribution, with the t-statistic (0.67) marked as a vertical dashed line. The location of the t-statistic on the curve indicates that it is not in the tail region, confirming that the result is not statistically significant;
- the cumulative distribution functions (CDFs) of both distributions in Figure 7 are plotted to compare the cumulative probability of obtaining a given measurement from each device. As shown, the CDFs of the two devices are very similar, further supporting the conclusion that there is no significant difference between the two systems.

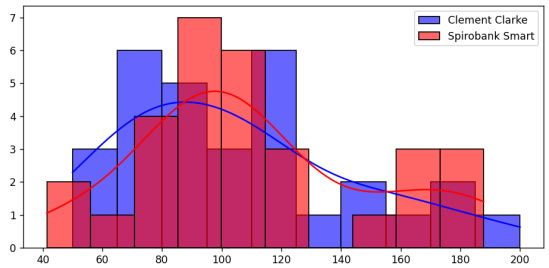

Fig. 4: Frequency distribution of measurements collected from the two devices

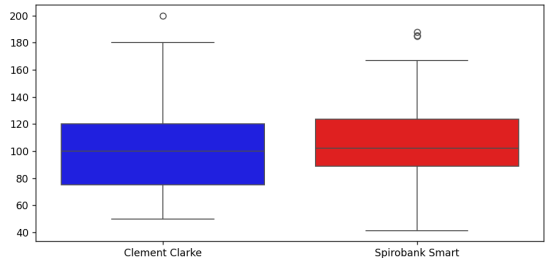

Fig. 5: Interquartile range (box) and median (line within the box) of the measurements collected from the two devices

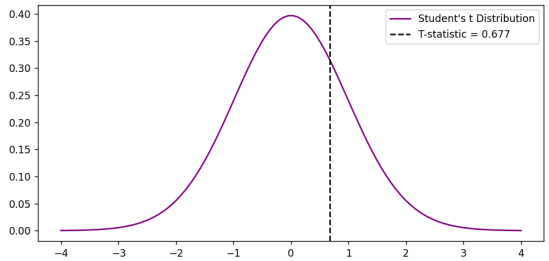

Fig. 6: Student's t-distribution probability density function with the t-statistic (dashed line)

V. Limitations and Future Works

The main limitation of this study lies in the original configuration of the application connected to the spirometer,

which "requires" the user to exhale through the mouth. This may confuse some subjects and lead to inaccurate results if proper attention is not paid. In the future, it might be worth considering making the application fully adaptable to this context, thereby enhancing its versatility and applicability across various pathological conditions. Additionally, to further improve patient comfort, it may be worth considering the use of an alternative to the standard anesthesia face mask, one that is better suited for detecting airflow from the nasal cavities without including the mouth. It should also be noted that this preliminary study was conducted on healthy subjects to validate the system. Subsequent testing will be carried out in patients under medical supervision. Future developments could focus on extending its application to other nasal obstructive diseases, integrating additional respiratory parameters, or evaluating its use in a broader patient population, including those with more severe forms of nasal obstructions.

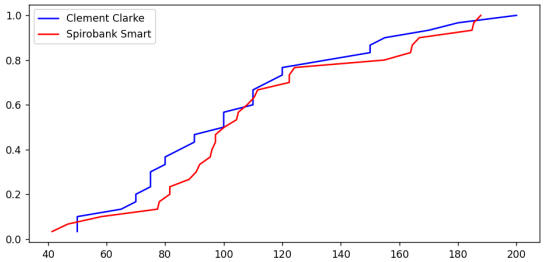

Fig. 7: Comparison of the cumulative distribution functions of the measurements collected from the two devices

VI. Conclusion

Telemedicine represents a fundamental advance in healthcare care, enabling physicians to provide remote care, reducing the need for in-person visits, and alleviating the burden on healthcare facilities. This is particularly crucial in managing chronic conditions such as obstructive nasal diseases, which significantly impact patients' quality of life and require continuous and periodic monitoring. In this study, we developed and implemented a telemedicine infrastructure for remote monitoring of obstructive nasal conditions. At its core is a customized commercial spirometer (Spirobank Smart by MIR), adapted to measure peak nasal inspiratory flow (PNIF) and integrated into a remote data management system for real-time measurement collection and visualization. To ensure the reliability of the recorded data, a dedicated measurement protocol was developed.The initial experimental phase, conducted on 30 healthy subjects, demonstrated that the PNIF values obtained using the Spirobank Smart were comparable to those measured with a standard hospital device. This validation confirms the feasibility of using the system for home-based monitoring, allowing direct transmission of respiratory data to healthcare professionals; obviously, validation on patients is essential.The proposed telemonitoring system provides an effective and accessible tool for patients with obstructive nasal disorders, enabling them to perform diagnostic tests independently and monitor multiple conditions using a single medical device.

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