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A COMPARATIVE ANALYSIS OF PEAK EXPIRATORY FLOW RATE MEASUREMENTS: A VALIDATION STUDY OF A MECHANICAL PEAK FLOW METER AGAINST A DIGITAL SPIROMETER

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ABSTRACT

Background: The measurement of Peak Expiratory Flow Rate (PEFR) is fundamental for diagnosing and monitoring obstructive airway diseases like asthma and COPD. While digital spirometry is the gold standard for pulmonary function testing in clinical settings, mechanical peak flow meters (PFMs) are widely used for home monitoring due to their portability and low cost. The agreement between these two devices is crucial for consistent patient management.

Materials and Methods: A cross-sectional, comparative study was conducted on 120 healthy non-smoking adults (60 males, 60 females) aged 18-60 years. Each participant performed PEFR maneuvers on both a Mini-Wright mechanical PFM and a Spiroexcel PC PFT digital spirometer in a randomized order, following American Thoracic Society/European Respiratory Society (ATS/ERS) guidelines. The highest of three acceptable readings from each device was recorded. Data were analyzed using paired t-tests, Pearson correlation and Bland-Altman analysis to assess mean differences, correlation, and agreement.

Results: The mean PEFR measured by the digital spirometer (521.5 ± 92.4 L/min) was significantly higher than that measured by the PFM (508.2 ± 98.6 L/min), with a mean difference of 13.3 L/min ($p=0.002$). A very strong, positive correlation was observed between the two devices ($r = 0.96$, $p < 0.001$). However, the Bland-Altman analysis revealed a systematic bias, with the PFM underestimating PEFR. The 95% limits of agreement were wide, ranging from -25.8 L/min to 52.4 L/min, indicating poor agreement between the individual measurements.

Conclusion: Although PEFR values from the mechanical PFM and digital spirometer are strongly correlated, they are not interchangeable. The PFM systematically underestimates PEFR compared to the spirometer, and the wide limits of agreement suggest that clinical decisions based on absolute values should not use data from these devices interchangeably. The PFM remains a valuable tool for serial self-monitoring of relative changes in an individual's lung function, but spirometry should be used for diagnostic purposes and for establishing a definitive baseline.

Keywords: Peak Expiratory Flow Rate, Spirometry, Peak Flow Meter, Respiratory Function Tests, Agreement Study, Bland-Altman Plot.

INTRODUCTION

Peak Expiratory Flow Rate (PEFR) is defined as the maximum flow rate generated during a forceful expiration, starting from total lung capacity.[1] It is a simple, reproducible measure of the caliber of large airways and is a cornerstone in the assessment, diagnosis, and management of obstructive respiratory diseases, particularly asthma and Chronic Obstructive Pulmonary Disease (COPD).[2] Regular monitoring of PEFR allows patients and clinicians to track disease progression, assess response to therapy, and predict impending exacerbations, thereby enabling timely intervention.[3]

The two primary instruments for measuring PEFR are the laboratory-based digital spirometer and the portable, mechanical peak flow meter (PFM). Digital spirometry, which adheres to stringent calibration and performance standards set by bodies like the American Thoracic Society (ATS) and European Respiratory Society (ERS), is considered the gold standard for pulmonary function testing.[4] It provides a comprehensive assessment of lung volumes and flow rates, including PEFR, Forced Vital Capacity (FVC) and Forced Expiratory Volume in one second (FEV1). However, its use is typically confined to hospitals and clinics due to its cost, size and need for trained operators.

In contrast, the mechanical PFM is an inexpensive, portable, and user-friendly device designed for patient self-monitoring at home.[5] Its widespread availability empowers patients to take an active role in their disease management, in line with modern chronic care models.[6] The clinical utility of the PFM depends on its ability to provide readings that are consistent and reflective of the patient's underlying airway status. Therefore, the accuracy and reliability of these devices compared to the gold-standard spirometer are of paramount clinical importance. An inaccurate PFM could lead to either a false sense of security or unnecessary anxiety and treatment escalation.[7]

Several studies have compared various models of PFMs with spirometers, often with conflicting results. Some have reported a strong correlation and acceptable agreement,[8] while others have highlighted significant discrepancies and systematic bias, with PFMs typically underestimating PEFR compared to spirometers.[9,10] These differences may be attributable to variations in device mechanics, study populations, and procedural protocols. With the continuous evolution of both spirometric technology and PFM manufacturing, there is an ongoing need to validate currently available devices.

A significant research gap persists in the direct comparison of widely used mechanical PFMs against contemporary, laboratory-grade digital spirometers within a general healthy adult population. Most studies are either dated, focus on pediatric populations, or are conducted exclusively in patients with established respiratory disease, where the effort-dependence of the PEFR maneuver may differ. Establishing the relationship between these two instruments in a healthy cohort provides a fundamental baseline for their clinical interpretation. Therefore, the present study aims to compare the PEFR values obtained from a widely used mechanical peak flow meter and a laboratory-grade digital spirometer in a sample of healthy adults and to evaluate the level of agreement between the two instruments.

MATERIALS AND METHODS

Study Design and Setting

A cross-sectional, comparative validation study was conducted at the Department of Physiology in Patna Medical College and Hospital, Patna, Bihar.

Study Population and Sample Size

A total of 120 healthy adult volunteers were recruited from the Hospital Staff and Medical Students via convenience sampling. Sample size was calculated using power analysis software to detect a mean difference of 10 L/min in PEFR with a standard deviation of 30 L/min, requiring a minimum of 116 participants for 80% power at an alpha level of 0.05. The sample was balanced for sex, with 60 males and 60 females.

Inclusion and Exclusion Criteria

Participants included were between 18 and 60 years of age, who provided written informed consent, and were able to understand and perform the required respiratory maneuvers. Exclusion criteria included any self-reported history of chronic respiratory diseases (e.g., asthma, COPD, bronchitis), acute respiratory tract infection within the past three weeks, a history of thoracic or abdominal surgery, cardiovascular instability, a smoking history of more than 5 pack-years, or pregnancy.

Instruments

1. **Digital Spirometer:** A Spiroexcel PC PFT laboratory-grade digital spirometer was used as the reference instrument. The spirometer software automatically recorded the highest PEFR from the flow-volume loop.
2. **Peak Flow Meter:** A standard-range Mini-Wright mechanical peak flow meter (Clement Clarke International, UK) with a scale from 60 to 800 L/min was used as the index instrument. The device was new and checked for function before the study commenced.

Procedure

Upon arrival at the laboratory, participants provided written informed consent. Demographic data, including age, sex, height (using a stadiometer), and weight (using a digital scale), were recorded. A brief medical and smoking history was taken.

The procedure for performing a PEFR maneuver was demonstrated to each participant by a trained technician. Participants were instructed to stand, take the deepest possible breath, seal their lips tightly

around the mouthpiece, and then blast the air out as hard and as fast as possible in a single blow.

Each participant performed PEFR measurements on both the digital spirometer and the mechanical PFM. To minimize learning or fatigue effects, the order in which the devices were used was randomized using a simple coin-toss method. A rest period of at least 15 minutes was provided between testing on the two devices. For each device, participants performed a minimum of three maneuvers, with a 5 minutes rest between each attempt. The maneuvers were deemed acceptable if they were free from artifacts such as coughing, hesitation, or a submaximal blast. The highest value from the three acceptable maneuvers for each device was recorded for analysis. All measurements were taken by the same technician to ensure consistency.

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY). The normality of data distribution was assessed using the Shapiro-Wilk test. Descriptive statistics were presented as mean ± standard deviation (SD) for continuous variables and as frequencies and percentages for categorical variables.

A paired-samples t-test was used to compare the mean PEFR values obtained from the spirometer and the PFM. The relationship between the two sets of measurements was evaluated using Pearson's correlation coefficient (r). To assess agreement, a Bland-Altman analysis was performed. The mean difference (bias) between the two methods (Spirometer PEFR – PFM PEFR) and the 95% limits of agreement (LoA), calculated as mean difference ± 1.96 × SD of the differences, were determined. A p-value of < 0.05 was considered statistically significant.

RESULTS

Participant Demographics

The study included 120 healthy adult participants, comprising 60 males (50%) and 60 females (50%). The demographic and anthropometric characteristics of the study population are summarized in Table 1. The mean age of the participants was 34.2 ± 11.5 years. Males were significantly taller and heavier than females, as expected.

Table 1: Demographic and Anthropometric Characteristics of Study Participants

Characteristic	Males (n=60)	Females (n=60)	Total (n=120)
Age (years)	35.1 ± 12.1	33.3 ± 10.9	34.2 ± 11.5
Height (cm)	176.4 ± 6.8	162.5 ± 5.9	169.5 ± 9.3
Weight (kg)	78.2 ± 10.5	64.1 ± 9.8	71.2 ± 12.4
BMI (kg/m²)	25.1 ± 3.1	24.3 ± 3.5	24.7 ± 3.3

Data are presented as mean ± standard deviation (SD).

Comparison of PEFR Values

The mean PEFR values obtained from the digital spirometer were consistently higher than those from the mechanical PFM across the entire cohort as well as within sex-stratified groups. As shown in Table 2, the overall mean PEFR was 521.5 ± 92.4 L/min for the spirometer and 508.2 ± 98.6 L/min for the PFM. This difference of 13.3 L/min was statistically significant ($p = 0.002$). A similar significant difference was observed in the male subgroup ($p = 0.005$), whereas the difference in the female subgroup did not reach statistical significance ($p = 0.061$).

Table 2: Comparison of PEFR Values (L/min) between Digital Spirometer and Peak Flow Meter

Group	Digital Spirometer (Mean ± SD)	Peak Flow Meter (Mean ± SD)	Mean Difference (Spirometer - PFM)	p-value
Overall (n=120)	521.5 ± 92.4	508.2 ± 98.6	13.3 ± 20.1	**0.002**
Males (n=60)	585.3 ± 75.1	569.8 ± 79.2	15.5 ± 18.9	**0.005**
Females (n=60)	457.7 ± 68.9	446.6 ± 71.3	11.1 ± 21.4	0.061

p-value calculated using paired-samples t-test. Bold values indicate statistical significance ($p < 0.05$).

Correlation and Agreement Analysis

Pearson correlation analysis revealed a very strong, positive, and statistically significant correlation between the PEFR values measured by the two devices for the overall sample ($r = 0.96$, $p < 0.001$) and for both male ($r = 0.95$, $p < 0.001$) and female ($r = 0.94$, $p < 0.001$) subgroups.

Despite the strong correlation, the Bland-Altman analysis indicated poor agreement. For the overall sample, the mean bias was 13.3 L/min, signifying that the PFM systematically underestimated PEFR compared to the spirometer. The 95% limits of agreement (LoA) were wide, ranging from -25.8 L/min to 52.4 L/min. This means that for any given individual, the PFM reading could be as much as 25.8 L/min higher or 52.4 L/min lower than the spirometer reading. The results of the correlation and agreement analyses are detailed in Table 3.

Table 3: Correlation and Bland-Altman Agreement Analysis

Group	Pearson's Correlation (r)	p-value	Mean Bias (L/min) (Spirometer - PFM)	Lower 95% LoA (L/min)	Upper 95% LoA (L/min)
Overall (n=120)	0.96	< 0.001	13.3	-25.8	52.4
Males (n=60)	0.95	< 0.001	15.5	-21.5	52.5
Females (n=60)	0.94	< 0.001	11.1	-30.8	53.0

LoA = Limits of Agreement (Mean Bias ± 1.96 SD of the difference).

DISCUSSION

The primary objective of this study was to compare PEFR measurements from a common mechanical PFM with a laboratory-grade digital spirometer. Our findings reveal three critical points: first, the mechanical PFM systematically underestimates PEFR values compared to the digital spirometer; second, while the measurements from the two devices are very strongly correlated, third, their level of agreement is poor, with wide limits that preclude their interchangeable use in a clinical context.

The finding of a statistically significant mean difference, with the spirometer yielding higher readings, is consistent with a substantial body of previous research.[9,10,11] This systematic underestimation by the PFM can be attributed to several factors. Mechanical PFMs operate on a simple piston-and-spring or vane mechanism, which may have higher internal resistance to airflow compared to the low-resistance. This higher resistance could slightly impede the maximal expiratory effort, resulting in a lower measured value. Furthermore, digital spirometers sample airflow at a high frequency, allowing for a more precise capture of the true peak flow, which may be missed by a slower-moving mechanical indicator.[7]

A key finding of our study is the strong Pearson correlation coefficient (r = 0.96) between the two devices. A high correlation indicates that the PFM and spirometer generally move in the same direction; that is, an individual with a high PEFR on the spirometer will likely have a high PEFR on the PFM. This strong linear relationship is encouraging, as it supports the utility of the PFM for monitoring trends in an individual's lung function over time.[12] For an asthma patient, tracking their PEFR daily with the same PFM can effectively identify a decline from their personal best, signaling a need to adjust medication or seek medical attention, regardless of the absolute value.

However, the distinction between correlation and agreement is critical and is highlighted by our Bland-Altman analysis. While correlation assesses the strength of a linear relationship, agreement assesses the extent to which the values from two methods are interchangeable.[13] Our analysis revealed a mean bias of 13.3 L/min and wide 95% limits of agreement (-25.8 to 52.4 L/min). These wide limits imply that for 95% of individuals, the difference between a PFM reading and a spirometer reading could fall anywhere within this 78.2 L/min range. Such a large potential discrepancy is clinically unacceptable if one device is to be substituted for the other for diagnostic purposes or for comparing absolute values against predicted norms.[8] For instance, a PEFR of 380 L/min on a PFM might correspond to a true spirometric PEFR of over 430 L/min, potentially crossing a threshold for a clinical decision. This lack of agreement reinforces the recommendation that a patient's PEFR "zones" (green, yellow, red) for their asthma action plan should be established using the same device—preferably their own PFM—rather than being based on a reading from a clinic spirometer.[14]

The strengths of our study include a balanced sample of healthy adults, randomization of device order to mitigate bias, and adherence to standardized ATS/ERS protocols for the PEFR maneuver. However, several limitations must be acknowledged. First, our study was conducted in a single center with a healthy population, so the findings may not be generalizable to patients with severe respiratory disease, in whom effort and technique may be more variable. Second, we evaluated only one brand of mechanical PFM. Different models may exhibit different performance characteristics and levels of agreement with spirometry. Finally, this was a cross-sectional study and did not assess the long-term consistency or durability of the PFM.

CONCLUSION

This study demonstrates that while PEFR values obtained from a mechanical peak flow meter and a digital spirometer are strongly correlated, they are not in sufficient agreement to be considered interchangeable. The mechanical PFM was found to systematically underestimate PEFR compared to the gold-standard digital spirometer, and the variability between individual measurements was clinically significant.

These findings have important implications for clinical practice. The digital spirometer should remain the definitive instrument for the diagnostic evaluation of respiratory function and for establishing a patient's absolute PEFR. The mechanical PFM, however, serves a distinct and valuable role as a tool for serial self-monitoring of

relative changes from a patient's personal best. Clinicians and patients should be aware of the inherent discrepancy between these devices and ensure that management plans, particularly asthma action plans, are based on consistent use of the same instrument.

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