RESEARCH PAPER

Use of Forced Oscillation Technique in Preoperative Patient Evaluation and Its Comparison with Spirometry

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ABSTRACT

Background: Preoperative pulmonary assessment is important for identifying patients at increased risk of perioperative respiratory complications. Although spirometry is widely used, it requires considerable patient cooperation and forced respiratory manoeuvres. The forced oscillation technique (FOT) is a non-invasive, effort-independent method that evaluates respiratory resistance and reactance during tidal breathing. This study evaluated FOT in preoperative patients and compared its findings with conventional spirometry.

Methods: This prospective study included 200 adult patients undergoing preoperative evaluation at Kempegowda Institute of Medical Sciences and Research Centre, Bengaluru. All participants underwent FOT followed by spirometry. Spirometric parameters included FEV_1/FVC and FEV_1 percentage predicted, while FOT parameters included R5, R20, R5–R20, and X5. Appropriate statistical tests were applied, with $P<0.05$ considered statistically significant.

Results: The mean age was 50.46 ± 13.40 years, and 60.0% were males. Mean FEV_1/FVC and FEV_1 percentage predicted were 76.45 ± 11.79% and 81.92 ± 13.25%, respectively. Spirometry was normal in 56.0% of patients, while 23.0%, 20.0%, and 1.0% had mild, moderate, and severe abnormalities, respectively. Mean R5, R20, R5–R20, and X5 were 4.44 ± 2.34, 2.61 ± 1.26, 1.50 ± 1.46, and −1.92 ± 1.61, respectively. FOT parameters differed significantly across spirometric severity categories (all $P<0.001$). R5 increased from 3.26 ± 0.67 in patients with normal spirometry to 9.94 ± 2.38 in those with severe impairment, while X5 became progressively more negative.

Conclusion: FOT demonstrated significant changes with increasing spirometric impairment and may provide a useful, non-invasive, effort-independent complementary method for preoperative pulmonary evaluation.

Keywords: Forced oscillation technique; FOT; spirometry; pulmonary function test; preoperative evaluation; respiratory impedance.

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INTRODUCTION

Preoperative pulmonary evaluation is an important component of perioperative risk assessment, particularly in patients undergoing thoracic, upper abdominal, pelvic, and major orthopedic procedures. Pre-existing or unrecognized respiratory dysfunction may increase the risk of postoperative pulmonary complications (PPCs), including atelectasis, pneumonia, respiratory failure, prolonged mechanical ventilation, and extended hospital stay. Therefore, accurate assessment of pulmonary function before

surgery may facilitate early identification of high-risk patients and guide appropriate perioperative optimization.Spirometry remains one of the most widely used pulmonary function tests for evaluating respiratory impairment in clinical practice. Conventional spirometric parameters, including forced expiratory volume in one second (FEV_1), forced vital capacity (FVC), and the FEV_1/FVC ratio, are useful for identifying and characterizing obstructive and restrictive ventilatory abnormalities. However, spirometry may have limited sensitivity for detecting early abnormalities involving the peripheral or small airways [1–3]. Furthermore, reliable spirometry requires adequate patient understanding, cooperation, and performance of technically acceptable forced respiratory manoeuvres. Consequently, obtaining reproducible measurements may be challenging in elderly individuals and patients with physical, cognitive, or respiratory limitations [1]. Increasing recognition of small-airway involvement in the early stages of respiratory disease has therefore stimulated interest in techniques capable of identifying functional abnormalities before they become evident on conventional spirometry [4–6].The forced oscillation technique (FOT), first described by DuBois et al. in 1956, provides a non-invasive method for assessing the mechanical properties of the respiratory system during normal tidal breathing [7]. FOT applies small-amplitude pressure oscillations of different frequencies to the respiratory system and measures the resulting pressure-flow relationship to determine respiratory impedance. Impedance comprises resistance and reactance, thereby providing information regarding airway calibre and the elastic and inertial properties of the respiratory system. Although FOT has been increasingly investigated in respiratory medicine, much of the available literature has focused on its application in obstructive airway diseases such as asthma [8].An important advantage of FOT is that measurements can be obtained during quiet tidal breathing without requiring forceful inspiratory or expiratory manoeuvres. Consequently, it is relatively effort-independent, requires less patient cooperation, and may be particularly suitable for individuals who have difficulty performing conventional spirometry [9–15]. Previous studies have suggested that oscillometry may also identify peripheral airway dysfunction that is not readily detected by conventional spirometric indices [9,14].Despite these potential advantages, evidence regarding the role of FOT in preoperative pulmonary evaluation and its relationship with conventional spirometry remains limited. Evaluating the agreement and differences between these techniques may help determine whether FOT can complement spirometry or provide a practical alternative in selected surgical patients. Therefore, the present study was designed to evaluate the use of forced oscillation technique in preoperative patients and to compare FOT-derived respiratory parameters with conventional spirometric measurements.

MATERIALS AND METHODS

This prospective study was conducted at Kempegowda Institute of Medical Sciences and Research Centre, Bengaluru, over a period of 18 months. The study population consisted of adult patients who were scheduled to undergo surgery and underwent preoperative pulmonary evaluation during the study period.

Sample Size Calculation

The sample size was estimated based on the expected relationship between preoperative spirometry and FOT findings, using data reported by Nakano et al. (2016). The calculation was performed using a 95% confidence level ($Z_{1-\alpha/2} = 1.96$), with the anticipated correlation coefficient between preoperative spirometry and FOT findings in the study sample taken as 0.60 and the corresponding population value as 0.47, with an allowable error of 0.05. Based on these, the minimum estimated sample size was 188 participants. To account for possible incomplete or technically unacceptable measurements and to obtain an adequate final sample, the sample size was rounded to 200 participants.

Study Population

Patients aged >18 years who were scheduled for surgery at the study institution and fulfilled the eligibility criteria were considered for inclusion. A total of 200 patients were included in the study.

Inclusion Criteria

Patients were included if they were aged >18 years, were scheduled to undergo a surgical procedure, and provided written informed consent for participation.

Exclusion Criteria

Patients aged <18 years and those who refused to provide informed consent were excluded. Patients with contraindications to pulmonary function testing were also excluded, including those with thoracic aneurysm; recent eye surgery within the preceding 6–8 weeks, including cataract, glaucoma, retinal, LASIK, or photorefractive keratectomy surgery; ruptured tympanic membrane, chronic suppurative otitis media, or recent middle or inner ear surgery; hemoptysis ; pregnancy; or active pulmonary tuberculosis. Patients with recent major cardiac events within the preceding three months, including myocardial infarction, unstable angina, or percutaneous transluminal coronary angioplasty, were excluded. Patients who were unable to perform acceptable spirometry were also excluded.

Data Collection

After confirming eligibility and obtaining written informed consent, demographic and clinical information was recorded using a predefined data collection form. Baseline variables included age, sex, relevant medical history, pre-existing comorbidities, medications, and recognized respiratory and other clinical risk factors. A detailed clinical examination was performed, and relevant investigations conducted as part of routine preoperative evaluation were recorded .All enrolled participants underwent both forced oscillation technique (FOT) and spirometry during the same preoperative visit. FOT was performed before spirometry because the forced respiratory manoeuvres required during spirometry could potentially influence subsequent measurements of respiratory resistance and reactance.

Assessment of Pulmonary Function

Forced Oscillation Technique

Forced oscillation measurements were obtained using the Antlia FOT device (I Caltech Solutions). The examination was performed with the participant seated comfortably with the neck maintained in a neutral position. A nose clip was applied, and participants were instructed to support their cheeks to minimize upper-airway shunting.

Participants breathed quietly through the mouthpiece at functional residual capacity using normal tidal breathing for approximately 30 seconds. The breathing pattern and lung-volume tracing were continuously monitored during the measurement. Recordings affected by swallowing, glottic closure, leakage around the mouthpiece, inadequate nose-clip sealing, irregular breathing, or acute hyperventilation were considered technically unacceptable and were discarded. Measurements were repeated until three to five technically acceptable recordings were obtained. The quality of measurements was additionally assessed using the device-derived coherence function wherever applicable. FOT-derived parameters reflecting respiratory-system impedance, including resistance and reactance, were recorded for subsequent analysis.

Spirometry

Spirometry was performed using a Pneumotrac with Spirotrac software (Vitalograph). The procedure was explained to each participant in a language they understood. Participants were examined in an upright sitting or standing position and were made comfortable before testing. Tight clothing was loosened, and loose dentures were removed when necessary. A nose clip was used where appropriate, and participants were instructed to form a tight seal around the mouthpiece.Participants were initially instructed to breathe normally and were subsequently asked to inhale completely to total lung capacity, followed by rapid, forceful, and complete expiration until no further air could be expelled. They were then instructed to inhale completely again to obtain an adequate flow-volume loop. Additional instructions and demonstrations were provided when required.A maximum of eight attempts was permitted to obtain technically acceptable and reproducible recordings. Spirometric manoeuvres were considered acceptable when there was adequate inspiration before forced expiration, no hesitation or false start, no cough during the early phase of expiration, no premature termination of expiration, and no significant artifact caused by improper mouthpiece positioning or tongue obstruction. Device zeroing and calibration were checked whenever inconsistencies between inspiratory and expiratory volumes were observed.The principal spirometric parameters recorded included forced expiratory volume in one second (FEV_1), forced vital capacity (FVC), and the FEV_1/FVC ratio, along with other available spirometric indices.

Outcome Measures

The primary outcome of the study was the comparison of pulmonary function measurements obtained by forced oscillation technique with those obtained by conventional spirometry during preoperative evaluation. The relationship between FOT-derived respiratory resistance and reactance parameters and conventional spirometric indices was assessed to determine the utility of FOT for detecting pulmonary functional abnormalities in preoperative patients.

Ethical Considerations

The study was initiated after obtaining approval and clearance from the Institutional Ethics Committee of Kempegowda Institute of Medical Sciences and Research Centre (KIMS/IEC/D179/M/2023). Written informed consent was obtained from all participants before enrolment. Patient confidentiality was maintained throughout the study.

Statistical Analysis

Data were entered and compiled using Microsoft Excel and subsequently analyzed using IBM SPSS Statistics for Windows, version 26.0. Quantitative variables were summarized as mean ± standard deviation (SD), while qualitative variables were expressed as frequencies and percentages.Appropriate statistical tests were applied according to the nature and distribution of the variables. The Student's *t*-test was used for comparison of continuous variables, where applicable, while the chi-square test was used for comparison of categorical variables. The relationship between spirometric and FOT parameters was assessed using appropriate correlation analysis. Results were presented using tables, figures, and graphs wherever appropriate. A two-sided P value <0.05 was considered statistically significant.

RESULTS

A total of 200 patients undergoing preoperative pulmonary evaluation were included in the study. The mean age of the participants was 50.46 ± 13.40 years. There was a male predominance, with 120 (60.0%) males and 80 (40.0%) females. Regarding smoking status, 89 (44.5%) participants were smokers, while 111 (55.5%) were non-smokers. The mean height and weight were 159.35 ± 9.69 cm and 62.28 ± 10.63 kg, respectively, while the mean BMI was 27.39 ± 5.99 kg/m² (Table 1).

Spirometric assessment showed a mean FEV_1/FVC ratio of 76.45 ± 11.79% and mean FEV_1 of 81.92 ± 13.25% predicted. Based on spirometric severity, 112 (56.0%) patients had normal pulmonary function, while 46 (23.0%) had mild, 40 (20.0%) had moderate, and 2 (1.0%) had severe impairment. Overall, 88 (44.0%) patients demonstrated a spirometric abnormality (Table 2; Figure 1).

Forced oscillation technique assessment demonstrated a mean R5 of 4.44 ± 2.34, ranging from 2.00 to 13.30, and a mean R20 of 2.61 ± 1.26, ranging from 0.33 to 8.10. The mean R5–R20 was 1.50 ± 1.46, while the mean X5 was −1.92 ± 1.61. Considerable variability in resistance and reactance measurements was observed across the study population (Table 3).

Smoking status showed a significant association with abnormal spirometric findings. Among the 89 smokers, 52 (58.4%) had abnormal spirometry, compared with 36 (32.4%) of the 111 non-smokers. Conversely, normal spirometry was observed in 41.6% of smokers compared with 67.6% of non-smokers. This association was statistically significant (P<0.001) (Table 4; Figure 2).

With respect to the type of surgical procedure, orthopedic surgeries were the most common, accounting for 91 (45.5%) patients, followed by abdominal surgeries in 83 (41.5%). Thoracic and pelvic surgeries accounted for 14 (7.0%) and 12 (6.0%) patients, respectively (Table 5; Figure 3).

A significant relationship was observed between spirometric severity and FOT parameters. Mean R5 increased progressively from 3.26 ± 0.67 in patients with normal spirometry to 4.07 ± 1.16 in mild, 7.89 ± 2.66 in moderate, and 9.94 ± 2.38 in severe impairment. Similarly, R20 increased from 2.31 ± 0.86 in the normal group to 4.43 ± 1.03 in the severe group. R5–R20 was higher in all abnormal spirometric categories compared with the normal group. X5 also became more negative with pulmonary impairment, with values ranging from −1.29 ± 0.59 in the normal group to −3.53 ± 0.99 in the severe group. Differences across spirometric severity categories were statistically significant for R5, R20, R5–R20, and X5 (all P<0.001) (Table 6). Overall, these findings demonstrated that worsening spirometric pulmonary function was accompanied by increased respiratory resistance and greater abnormalities in respiratory reactance measured using FOT.

Table 1. Baseline demographic and anthropometric characteristics of the study population (n=200)

Characteristic	**n (%) / Mean ± SD**
Age (years)	50.46 ± 13.40
Sex	
Male	120 (60.0)
Female	80 (40.0)
Smoking status	
Smoker	89 (44.5)
Non-smoker	111 (55.5)
Height (cm)	159.35 ± 9.69
Weight (kg)	62.28 ± 10.63
BMI (kg/m²)	27.39 ± 5.99

Table 2. Spirometric findings and severity of pulmonary dysfunction (n=200)

Parameter	**n (%) / Mean ± SD**
FEV_1/FVC (%)	76.45 ± 11.79
FEV_1 (% predicted)	81.92 ± 13.25
Spirometry severity	
Normal	112 (56.0)
Mild	46 (23.0)
Moderate	40 (20.0)
Severe	2 (1.0)
Any spirometric abnormality	**88 (44.0)**

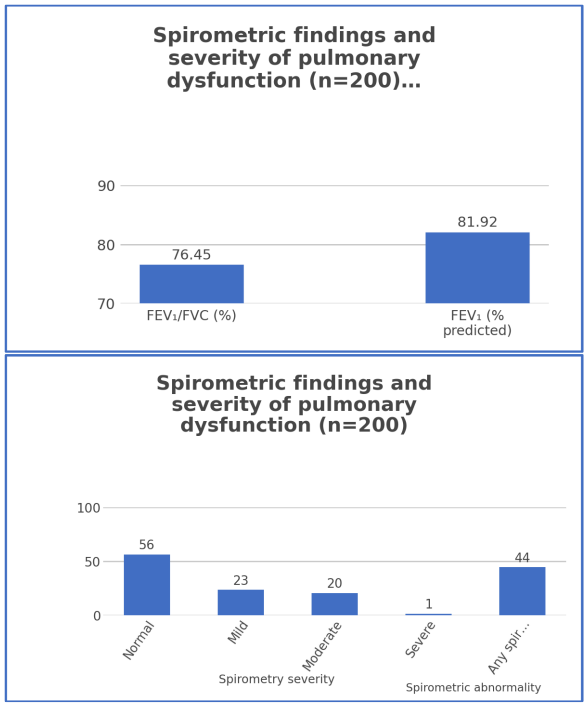

Figure 1 Spirometric findings and severity of pulmonary dysfunction (n=200)

Table 3. Forced oscillation technique parameters in the study population (n=200)

FOT parameter	Mean ± SD	Minimum	Maximum
R5	4.44 ± 2.34	2.00	13.30
R20	2.61 ± 1.26	0.33	8.10
R5–R20	1.50 ± 1.46	−1.72	6.08
X5	−1.92 ± 1.61	−7.50	2.29

Table 4. Association between smoking status and spirometric pulmonary function (n=200)

Smoking status	Normal spirometry n (%)	Abnormal spirometry n (%)	Total n (%)	P value
Smoker	37 (41.6)	52 (58.4)	89 (100.0)	**<0.001**
Non-smoker	75 (67.6)	36 (32.4)	111 (100.0)	
Total	**112 (56.0)**	**88 (44.0)**	**200 (100.0)**	

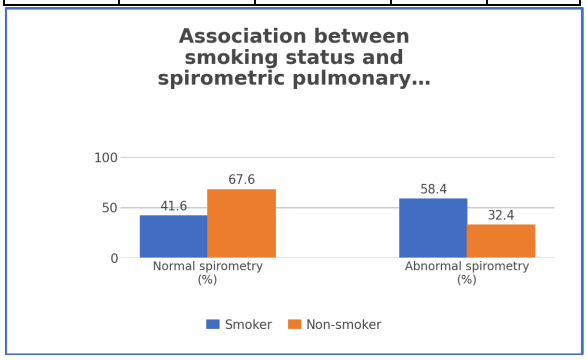

Figure 2 Association between smoking status and spirometric pulmonary function (n=200)

Table 5. Distribution of patients according to type of surgery (n=200)

Type of surgery	n (%)
Orthopedic	91 (45.5)
Abdominal	83 (41.5)
Thoracic	14 (7.0)
Pelvic	12 (6.0)
Total	**200 (100.0)**

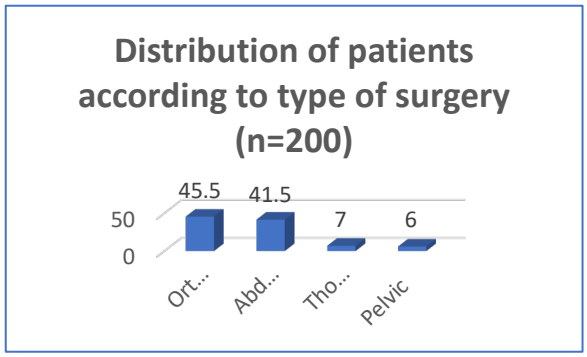

Figure 3 Distribution of patients according to type of surgery (n=200)

Table 6. Comparison of FOT parameters according to spirometric severity (n=200)

Spirometry severity	n	R5, Mean ± SD	R20, Mean ± SD	R5–R20, Mean ± SD	X5, Mean ± SD
Normal	112	3.26 ± 0.67	2.31 ± 0.86	0.87 ± 0.69	−1.29 ± 0.59
Mild	46	4.07 ± 1.16	2.72 ± 0.95	2.49 ± 1.55	−2.88 ± 1.85
Moderate	40	7.89 ± 2.66	3.22 ± 2.01	2.08 ± 1.97	−2.49 ± 2.37
Severe	2	9.94 ± 2.38	4.43 ± 1.03	2.72 ± 2.80	−3.53 ± 0.99
P value		**<0.001**	**<0.001**	**<0.001**	**<0.001**

DISCUSSION

The present prospective study evaluated the utility of the forced oscillation technique (FOT) in preoperative pulmonary assessment and compared oscillometric measurements with conventional spirometry among 200 patients undergoing various surgical procedures. The findings demonstrated significant relationships between FOT-derived resistance and reactance indices and conventional spirometric parameters, supporting the potential role of FOT as a complementary method for identifying respiratory dysfunction during preoperative evaluation.The mean age of the study population was 50.46 ± 13.40 years, and 60% were males. In comparison, Nakano et al. [16] studied 26 predominantly male patients (88.5%) with a median age of 68 years. Fujii et al. [17] evaluated 168 patients with a mean age of approximately 68 years and a male-to-female ratio of 87:61, while Kaku et al. [18] reported a mean age of 69.2 years with male predominance. Thus, although our patients were relatively younger, the male predominance was consistent with these studies. In contrast, Lauhkonen et al. [10] investigated a pediatric population with a mean age of 10.9 ± 3.6 years.Smoking was reported by 44.5% of our patients. Nakano et al. [16] reported 19.2% current smokers and 65.4% former smokers, while Kaku et al. [18] found a smoking history in 77.3% of participants and pre-existing respiratory disease in 43.2%. The mean BMI in our study was 27.39 ± 5.99 kg/m², compared with a median BMI of 23.7 kg/m² reported by Nakano et al. [16].Conventional spirometry demonstrated a mean FEV_1/FVC of 76.45 ± 11.79% and mean predicted FEV_1 of 81.92 ± 13.25%. Overall, 56% of patients had normal spirometry, while 23%, 20%, and 1% had mild, moderate, and severe abnormalities, respectively. Nakano et al. [16] similarly reported relatively preserved preoperative pulmonary function, with median %FVC of 98% and FEV_1/FVC of 74.3%. Fujii et al. [17] reported pulmonary dysfunction in approximately 40% of patients and significantly reduced FEV_1-related indices in obstructive and combined impairment groups. These findings are broadly comparable to the 44% prevalence of abnormal spirometry observed in our population.FOT demonstrated mean R5, R20, R5–R20, and X5 values of 4.44, 2.61, 1.50, and −1.92, respectively. Importantly, these oscillometric indices were strongly associated with conventional spirometry. FEV_1/FVC correlated negatively with R5 ($r=-0.671$), R20 ($r=-0.505$), and R5–R20 ($r=-0.608$), while predicted FEV_1 demonstrated its strongest inverse correlation with R5 ($r=-0.770$; $P<0.001$). Conversely, X5 correlated positively with FEV_1/FVC ($r=0.587$) and predicted FEV_1 ($r=0.488$), indicating increasingly negative reactance with worsening pulmonary function.These observations are supported by Lauhkonen et al. [10], who demonstrated inverse correlations of oscillometric resistance with FEV_1 ($r=-0.56$), FEV_1/FVC ($r=-0.61$), and FEF25–75% ($r=-0.63$). Balasundaran et al. [19] similarly demonstrated significant inverse relationships between R5, R20, and R5–R20 and conventional

spirometric indices. Batmaz et al. [9] showed that R5, R20, R5–R20, and X5 could identify airway obstruction, while Saadeh et al. [12] reported correlations of R5 (r=−0.478), R20 (r=−0.401), and X5 (r=0.267) with FEV_1. Miyoshi et al. [20] also demonstrated significant correlations of R5 with FEV_1 (r=−0.502) and X5 with FEV_1 (r=0.546), while Nair et al. [21] reported an inverse relationship between R5 and FEV_1 (r=−0.40).A progressive alteration in FOT parameters was additionally observed with increasing spirometric severity. Mean R5 increased from 3.26 in patients with normal spirometry to 9.94 in severe impairment, while X5 became more negative from −1.29 to −3.53; differences across severity categories were significant (P<0.001). Nakano et al. [16] and Kaku et al. [18] similarly demonstrated worsening resistance and reactance parameters in association with perioperative pulmonary deterioration.

CONCLUSION

The forced oscillation technique (FOT) demonstrated a significant association with conventional spirometric parameters in patients undergoing preoperative pulmonary evaluation. Increasing spirometric severity was accompanied by higher airway resistance (R5, R20, and R5–R20) and more negative reactance (X5). FOT therefore appears to be a useful, non-invasive, and effort-independent method for detecting pulmonary dysfunction. It may serve as a valuable complementary tool to spirometry, particularly in patients who have difficulty performing forced respiratory manoeuvres.

LIMITATIONS

This was a single-center study with a relatively limited sample size, which may restrict the generalizability of the findings. The study primarily compared FOT with spirometry and did not evaluate its association with postoperative pulmonary complications or long-term clinical outcomes. Additionally, the influence of potential confounding factors such as comorbid respiratory diseases, smoking exposure, and type of surgery was not comprehensively adjusted for.

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