Research Article

Spirometry: An Interpretation of Patterns and Clinical Implications

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Introduction: In general practice spirometry is under utilized in the diagnosis of the common respiratory symptom like breathlessness. A standardized forcible expiratory blow inside the spirometry machine followed by a force inspiratory maneuver displays various data related to flow of air in the lungs in the form of a flow-volume loop and volume-time tracings. A valid reporting as per ATS criteria is prerequisite for the interpretation and then compared with a predicted values of an individual.

Results: The main four parameters FVC, FEV1, ratio of FEV1/FVC and peak expiratory flow (PEF) are studied in patients to categorized them in various patterns; e.g. A) Normal pattern (40%), B) Obstructive flow pattern (15%); C) Restrictive (1%); D) Mixed pattern (28%); E) Obstructive (3%); and F) Mixed pattern (13%) with dominant obstructive/pseudo restrictive. A significant BD effect was observed in 28% (32/115) participants with having normal spirometry, while 40% (70/175) BD effect was observed among abnormal spirometry patterns. A low CPF was detected in 91(31%) of case and similarly, a value of less than 1L/sec PIFR was observed in 23 (8%) cases and thus not suitable for the DPI device. An overall restrictive PRISM in 11(4%), obstructive PRISM in 61 (21%) cases were also detected.

Discussion: Once the basic four parameters were identified and grouped together in various patterns, it becomes easy to understand the underlying ailment. These patterns enable differential diagnosis and help to customize management. The BD therapy could be planned and given to all who had produced a significant or partial response. A PIFR value of more than 1 liter/second would be required for the dry powder inhaler (DPI); otherwise, a device like MDI with a spacer or nebulizer should be preferred. Similarly, a normal adult should have more than 4L/Sec of PEFR, which is sufficient to clear the secretion as cough peak flow (CPF). Broadly a breathing exercises for the restrictive disorders, diaphragmatic and purse lip breathing for the obstructive pattern is recommended with periodic reassessment with spirometry. An additional detection of PRISM (preserved ratio impaired spirometry) cases could advise preventive measures, e.g., smoking cessation, etc., to minimize the risk of future disease load.

Conclusion: Spirometry is an important tool in evaluating shortness of breath and other respiratory symptoms which could be due to neuromuscular, pleural, parenchymal, and small or large airways abnormalities. It has a crucial role in differential diagnosis and dynamic volumetric assessment of a forceful expirational and inspirational activities. A newer version of spirometry or advanced technology equipment like FENO and oscillometry have become widely acceptable as thet are free from strict forceful maneuver (e.g. easy usual breath suitable for children and ICU patient), they are handy and cost effective and serve as alternate future modality.

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Introduction

The spirometry test detects various aspects of pulmonary functions, in spite it remained under used/ utilized in the clinical implications for diagnosis and therapeutic assessment of underlying causes of dyspnea.[1] The atmospheric air is inhaled and exhaled during each breath, which reaches through the trachea to the smaller bronchioles and up to the alveoli, via the movement of the respiratory apparatus. The function of the respiratory apparatus is controlled by the central nervous system, chemoreceptors, and the neuromuscular activity of the thoracic wall and diaphragm, which may alter the volume, flow, and time taken for the maneuver. Similarly, the natural elastic recoil capacity of the lung (increases in fibrosis or decrease/loss in emphysema) and airway resistance with or without bronchospasm (which changes the diameter of airways) may also alter the scenarios. The movement of air either inhaled or exhaled depends on the volume of air moving at which speed, i.e., flow rate, is a crucial issue, and the flow of air is recorded in a tracing form by the spirometer machine for interpretation.

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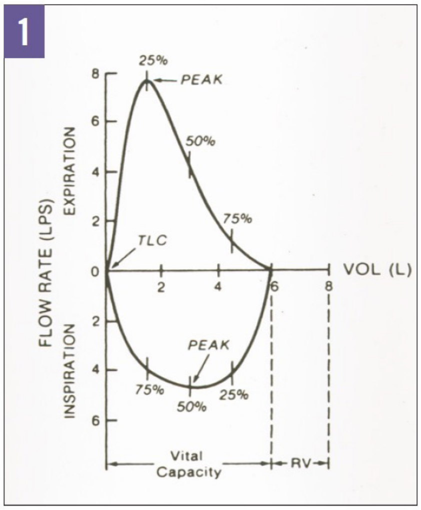

Figure 1: Example of Flow volume loop on spirometry

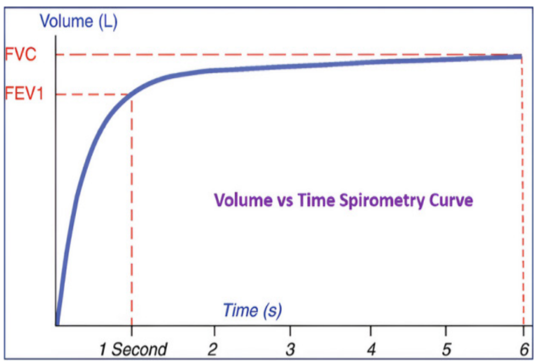

Figure 2: Example of Volume time curve on spirometry

Procedure/DATA generation

A standardized spirometry testing procedure, as per ATS/ ERS criteria or the Indian chest society consensus, is a prerequisite for the analytic procedure.[2-4] A most commonly used and acceptable maneuver for spirmetry test is to voluntarily fully fill the lungs by insiration/ inhalation of air and then quickly and forcibly expired the air in the machine till a complete emptying of lung is achieved is called force vital capacity (FVC) and that may take >6 seconds and then quickly to inhale forcibly to fully refill the lungs by inspiration. This maneuver is recorded in the form of a flow & volume in a loop-shaped curve having both the expiratory and inspiration curves (Figure 1). The analysis of the Flow-Volume Loop will explore the individual FVC or the force expiratory volume and a flow rate of air during force expiration (peak expiratory flow rate, i.e., PEFR), and similarly, the inspiration part will reveal the peak inspiratory flow rate, i.e., PIFR. The volume-time is another curve (Figure 2) depicting the force expiratory volume passed during the first second (FEV1). The performance of an individual is then compared with the expected or the predicted values[5] and that data is generated by an inbuilt setup in the machine itself, considering age, weight, height and ethnicity of the performer.

The normal values of FVC and FEV1 may swing between (80–120%), which is 20 percentiles on either side of normal, e.g. Lower and upper limit of normal (LLN and ULN). A repeat/post-test is done after a standardized dose of bronchodilator (BD) to assess its effectiveness on FVC and FEV1 [1].

The ratio of FEV1/FVC < 70% on post-test is deemed to be considered an obstructive pathology. Similarly, the FVC of < 70% of the predicted is taken as a restrictive ailment, and the decreased PEF and FEV1 (<80%) are considered obstructive spirometry. The interpretation of data enables distinguishing Obstructive, restrictive and mixed patterns of lung diseases. Pathological sites could also be identified as neuromuscular deficit of the respiratory pump/apparatus, airway resistance (intra or extra thoracic), dynamic airway compression with or without air trapping, narrowing of air way lumen due to bronchospasm, and at the parenchyma level due to emphysema or fibrosis. Spirometry is definitely an important complementary tool/modality for respiratory specialty; however, on its own, spirometry is useless unless a patient's history, clinical findings, relevant investigations with radiological imaging etc taken all together are not considered. Thus, to understand the clinical significance of spirometry data, the defects/ deficits need to be arranged in various patterns to better understood specially at primary and secondary health services. The present study was done at rural based medical college.

Material and Methods

All the cases with respiratory problems who underwent spirometry in the outpatient department of Respiratory Medicine were included for analysis in the present study, after excluding active infectious lung disease. A pre and post-spirometry test was performed with standardize maneuver and doses of BD.

Result

A total of 419 spirometry reports were performed during the study period and among them, 290 (69%) spirometry reports were considered for analysis in the present study who meet the standard criteria. There were 181 (62%) males and 109 (38%) females with a mean age of 45.5 years. An abnormality in four main parameters/ indicators of spirometry, i.e., FVC, FEV1, ratio of FVC/FEV1 and PEF (peak expiratory flow) were identified/ recognized to form groups of similar patterns. The ratio of FEV1/FVC is the key factor to distinguish normal from obstructive, restrictive, and mixed categories. The resultant patterns may have single, double, or multiple abnormalities, which were broadly divided into two categories: with a normal ratio (A–D) and decreased ratio of FEV1/FVC ('E' & 'F') are displayed in Table 1 with possible inferences.

Group A to D

A common normal FEV1/FVC ratio was observed in all these groups, which means no gross obstructive pathology exist but they still differ in other aspects.

- 'A' group, all four data were within a normal range, i.e., normal pattern, but the BD effect was not included and later on displayed in Table 2. Among group 'A', the 6 cases (2%) were detected with restrictive PRISM (FVC <80% but >70% with normal FEV1/FVC ratio).
- The 'B' group had exclusively diminished peak expiratory flow (PEF) due to an obstructive flow pattern—example: Bronchial asthma, ABPA, bronchiectasis, neuromuscular deficits, etc. A low force expiratory flow (FEF) rate of less than 4 L/second in an adult is considered to be inadequate and cannot completely clear the airways' secretions. These lower FEF cases may have recurrent LRTI or pneumonia and may create a problem in post OP thoraco-abdominal surgery due to retained secretions.
- 'C' group had <70% FVC value with normal or supra-normal ratio suggestive of restrictive disease pattern and the examples may be ILD, sarcoidosis, neuromuscular disorder, etc.
- 'D' group had Low FEV1 and low FVC, suggestive of mixed pattern or restrictive pattern with normal or supra normal ratio example i.e. ILD with UIP pattern.

Group E and F

A decreased FEV1/FVC ratio below LLN (<70%) suggestive of an obstructive pattern.

- 'E' group had an absolute obstructive pattern with decreased in FEV1, FEV1/FVC and PEF with normal FVC (> LLN), example COPD.
- 'F' group had decreased all four parameters, suggestion of mixed pattern found in advance diseases with distorted architecture example could be CPFE, bullous lung disease, ILD with UIP pattern, BOOP/COP, sequelae of TB cases, post OP case of lobectomy, etc.

Interpretations of Bronchodilator Effect (Table 2)

A significant increase in volume of FVC and or FEV1 after BD was recorded (Table 2) and the analysis revealed that there were disproportionate effect on FVC (Numerator) and FEV1 (Denominator). The BD effect differs in various groups or patterns of spirometry and these differences were sufficient to change the scenario of the FEV1/FVC ratio. The observations and interpretation could be summarized as;

- Among the 115 normal pattern spirometry data group (A), a significant BD effect was observed in 28% (32) cases, while in the remaining 175 cases of the total 290 with abnormal data (group B to E), 40% (70/175) documented

Table 1: The Patterns of spirometry

Groups	*FVC*	*FEV1*	*FEV1/FVC*	*PEF*	*Number of defect*	*Number of Cases (%)*	*Inference of various Patterns*
A	N	N	N	N	0	115 40 %	It does not rule out lung disease if values are near LLN or the effect of BD is not performed refer (Table 2). . (A) Normal Pattern
B	N	N	N	↓	**1**	42 15%	Flow limitation: FEV1 may be LLN with ↓Flow, Upper airway obstruction, ABPA; Bronchial Asthma , Neuromuscular (B) Obstructive flow Pattern
C	↓	N	N	N	1	4 01%	Restrictive defect: (< 70%) Low reserve, post pneumenectomy, Atelectasis, ILD, large PLEF, etc (C) Restrictive Pattern
D	↓	↓	N	N	**2**	80 28%	Low FEV1 and low FVC: Normal or supernormal FEV1/FVC: Neuromuscular, COP, fibrosing alveolitis (D) Mixed Pattern- Dominant Restrictive
E	N	↓	↓	↓	**3**	10 03%	Intrapulmonary airflow obstruction: BA, COPD, Ch Bronchitis, Bronchiectasis (E) Obstructive Pattern
F	↓	↓	↓	↓	4	39 13%	Advance distorted lung architect: COPD, Bullous lung disease, CPFE, TB, ILD, Bronchiectasis: kyphoscoliosis, Pleural and thoracic cage, (F) Mixed Pattern-Dominant Obstructive/ pseudorestrictive
						290	

Table 2: A Significant Bronchodilator effect on FVC & FEV1

FVC	*FEV1*	*FEV1/FVC*	*PEF*	*Number of defect*	*Number of Cases (N)*	*Significant BD Effect Out of (N)*	*% Effect of Bronchodilators on FVC & FEV1*				
							Both responded FVC & FEV1 (X)	*Exclusive on FVC(Y)*	*Exclusive on FEV1(Z)*	*FEV1/FVC Ratio*	*Ratio*
N	N	N	N	0	(A)115	32 (28%)	14 (44%)	14(44%)	04 (12%)	18 : 28	.64
N	N	N	↓	1	(B) 42	21 (50%)	8 (38%)	10 (48%)	03 (14%)	11 : 18	.61
↓	N	N	N	1	(C) 04	01 (25%)	1 (100%)	0	0	01 : 01	1.0
↓	↓	N	N	2	(D) 80	29 (36%)	15 (52%)	05 (17%)	09 (31%)	24 : 20	1.2
N	↓	↓	↓	3	(E) 10	05 (50%)	01 (20%)	04 (80%)	(0%)	01 : 05	.2
↓	↓	↓	↓	4	(F) 39	14 (36%)	04 (29%)	10 (71%)	0 to -14	0 : 14	.07
				total	290	102(35%)	43 (42%)	43 (42%)	16 (16%)	59 : 86 X+Z vs X+Y	.69

Table 3: Prevalence of PRISM

No. of Cases	*FVC < 80 % Below LLN*	*FEV1 <80 % Below LLN*	*FEV1/ FVC Ratio*	*Inference*	*Group/Pattern*	
A-115	6 cases	N	N	↓ FVC with Normal Ratio	A	06 cases Restrictive PRISM
B-42	5 cases	N	N	↓ FVC with Normal Ratio	B	05 cases Restrictive PRISM
C-04	< 70%	N	N	FVC < 70 % (Restrictive)	C	04 Restrictive DISEASE
D-80	< 80%	< 80%	N	<80 FEV1, Normal Ratio ↓ FVC ↓FEV1, Normal Ratio	D	61 Obstructive PRISM 19 Pseudo PRISm
E-10	N	< 80%	< 0.7	Obstructive Pattern ↓ Ratio	E	49/290 Obstructive Disease and NonPRISM
F-39	< 80%	< 80%	< 0.7	Mixed Pattern ↓ Ratio	F	
290				Restrictive PRISM 11(4%),ObstructivePRISM 61(21%), PseudoPRISM 19(7 %)		

a significant BD effect. However, an overall significant bronchodilator (BD) effect was observed in 35% (102/290) of the participants. It shows the diagnostic and therapeutic utility and the role of the BD test.

- Among these 102 cases with significant BD effect, the FVC responded far better than the FEV1. It was observed that a quantitative increase of FVC was more than FEV1, that is, 84% (86 out of 102) *versus* 58% (59 out of 102), respectively, which resulted in the detection of more obstructive cases.
- A disproportion response of BD on FVC and FEV1 is likely to alter the ratio of FEV1/FVC (e.g., numerator up on denominator). Thus, whenever the denominator (FVC) disproportionately increases, the ratio has to decline towards the obstructive ailments. A reverse or reciprocal may be observed in restrictive pathology when the increase of FVC remained poorer than the ratio may be normal or supernormal. This may also be due to ↑ the natural recoil capacity of the lung due to lung fibrosis (ILD is an example).
- The pattern 'B' showed isolated reduction of peak expiratory flow (PEF) in 14% (42/290) of cases, i.e., obstructive flow pattern and almost all had responded with BD; however, 50% cases showed a significant BD effect. The underlying cause could be bronchial asthma, upper airway obstruction, ABPA, etc.
- The pattern 'C' and 'D', a total of 84 individuals with basic abnormal, i.e., <80% FVC or FEV1, with normal or LLN ratio (FEV1/FVC), also responded with BD in 36% cases. Among all patters this was the only one having a poor responder to FVC than FEV1 (24:20)
- The patterns 'E' and 'F' already had a low ratio that further showed deterioration due to poorer BD effect on FEV1 than FVC due to air trapping, as happened in advance cases of COPD.

Discussion

Spirometry is an essential diagnostic tool and also helps in monitoring and evaluation of respiratory symptomatic, especially the presence of shortness of breath and wheeze. It is reproducible and has minimal to limited contraindications and side effects. The first step of analyzing the spirometry report is to look for the validity and verify that the test is OK, then find out the abnormalities in the main parameters. The spirometry machine provides volumetric information of FVC, FEV1 (liters per second) and their ratio (FEV1/FVC in percentage) with FEF (Lit/sec) of the individuals. These four basic parameters, in different combinations, form various groups/patterns, which are displayed in Table 1, and could help in differential diagnosis to understand the underlying ailment. M.R. Miller [6] has also mentioned the four major groups of abnormalities, while V.C. Moore [4] had remained precised to only three abnormal groups, e.g. Obstructive, restrictive and mixed patterns. However, the present study considered some additional patterns (Table 1), e.g., normal group 'A' (who had respiratory symptoms or signs and documented BD effect) and group 'F', which includes all together with the four basic abnormalities, thus it further succeeded in differentiating underlying pathology. The present study remained concise to simple spirometry, which could easily be performed at peripheral institutions without considering slow vital capacity (SVC) and maximum voluntary ventilation (MVV). Similarly, the body plethysmography and DLCO, the high-tech equipment, could help to further delineate a precise diagnosis, but were not included.

A simple spirometry enable to detect both obstructive and restrictive diseases even without BD test but the BD test is mandatory because according to the gases law of the Poiseulle's equation that a small increase in radius of bronchus has a big effect on flow of air; for example, if the radius of an airway is doubled from 1 to 2 mm, the flow rate through the tube increases 16-fold. The inverse is also true, which means halve the radius, then the flow reduces 16-fold. It is worthwhile to mention that in the airways, the bronchial muscles are located in the far periphery up to the alveolar duct; thus, the study of bronchodilator effect is an integral and essential part of spirometry. It helps to assess post-bronchodilator response with an increase of FVC and or FEV1 by >200 mL or >12% is considered significant. Our study revealed a significant BD effect, even in a normal spirometry pattern ('A'), which is the best example, and the BD therapy enable to improved the respiratory symptoms among them (Table 2).

The FEV1% and PEF% are the components of FVC and both of them depend on the neuromuscular efforts of the patient, but are not always equal. The PEF underestimates FEV1, especially with less severe airway obstructions, as in 'B' pattern, and overestimates as in 'E' and 'F' with severe obstructions.[7] Our study revealed an isolated decreased PEF (pattern 'B') in 42 (15%) cases with normal rest of the data (Table 1), and more than 50% showed significant BD effect (Table2), while partial BD effect was also observed in the rest of the cases, and all of them deserved BD therapy. M Brennan et al mentioned that cough peak flow is a fraction/part of the PEF and about 270 L/Minute (or > 4L/Second) is required for an effective cough in adults other wise the lung secretion may be retained.[8] These retained secretions may lead to recurrent pneumonia and or create postoperative respiratory problems after thoraco-abdominal surgery [8]. Damaraju V et al mentioned that PEF is effort-dependent and depends on clearing of large airways, while FEV1 is effort independent and measures both large and small airway functions so with a severe obstruction in the later stage, the intrathoracic pressure further raised will lead to dynamic compression of small airways, thus due to air trapping, the FEV1% reduces more than the PEF%.[9]

Obstructive pattern

A reduced ratio of FEV1/FVC below the LLN of the predicted value is recognized as an obstructive pathology [1] and found with asthma, COPD, bronchiolitis, cystic fibrosis, bronchiectasis, and airway tumors, etc., as observed in 'E' and 'F' patterns (Table 1) in the present study. However, a value of <70% of the ratio is diagnostic of COPD and could be less responsive to the BD test in comparison to PEF or bronchial asthma.

Restrictive pattern

Isolated reduced FVC was detected in only 4 (1.4%) cases ('C' of Tables 1 and 2) and among them, only 1 case had shown improvement with the BD test. However, these cases may need to be evaluated for neuromuscular, chest wall deformity, Pleural pathology, i.e., fibrosis, hydro, or pneumothorax, etc. A body plethysmography is used to measure total lung capacity (TLC), which may be required to diagnosed restrictive pattern, but it may be suspected with reduced FVC below LLN or below 70%, or when a normal or increase FEV1/FVC ratio is present [1]. Some of the other common conditions with loss of functioning lung parenchyma, e.g., diffuse parenchymal lung diseases, COP or BOOP, lung collapse/atelectasis, pneumonia and post-lung resection, etc., could be the underlying factor responsible for the restrictive pattern.

Mixed pattern

In the present study, a low FEV1 below LLN was observed in D, E and F patterns (Table 1) indicates airflow obstructive ailment, while simultaneous low FVC was also present in D and F, which denotes additional restrictive pathology called the mixed pattern. These mix pattern cases required additional customized efforts to detect underlying pathology and some of the examples could be like a more advance case of COPD with air trapping and or bullous disease, PLCH, sarcoidosis with fibrosis and distorted airways, advance cases of ILD with UIP pattern, asthma COPD overlap syndrome (ACOS), combined pulmonary fibrosis and emphysema (CPFE), etc. These mixed pattern spirometry could either be Obstructive or restrictive predominant, with variable BD responsive.

Preserved ratio impaired spirometry (PRISM) is a pulmonary function pattern characterized by a FEV1/FVC ratio of greater than 0.70, with FEV1 of less than 80% of the predicted value after the post-bronchodilator test. A low FEV1 situation denotes a definite airways obstructive without full filling the criteria for diagnosis of COPD (ratio <70%) and these types of cases could be the precursor and most likely to convert to COPD [(10)]. Huang et al had mentioned an estimated 7 to 13% prevalence globally, while various studies from Latin America, Denmark, and Malawi reported a prevalence of 5, 17.3, and 20.1%, respectively.[(5)] Our study revealed restrictive and non-restrictive PRISM in 4% (11/290) and 21% (61/290) of cases. These cases had a normal ratio of FEV1/FVC, while basic values of FEV1 and or FVC were <80% of the predicted as per Table 3. Thus, the PRISM warned or forecast for a concealed and hidden abnormality and could be aware and insists to take a preventing action, for example, smoking cessation, protection from dust/pollution exposure and respiratory Yogic interventions.[(11)] Shinichiro Miura et al had analyzed a multicenteric study data of 11,246 spirometry from five health care centers and concluded that the categorized restrictive PRISm (FEV1/FVC $\geq$ 0.7, FEV1 < 80% and FVC < 80%) and non-restrictive PRISm (FEV1/FVC $\geq$ 0.7, FEV1 < 80%, and FVC $\geq$ 80%), do not follow the conventional obstructive and restrictive criteria. He further mentions that these cases may be a precursor of COPD and require regular monitoring.[(12)]

Inhaler therapy is an integral and essential part of respiratory medicine, which may include drugs like bronchodilators (BD), steroids, muscarinic antagonist etc are available in various combinations and in different devices.[(13)] Spirometry is also concerned with whether the patient can generate sufficient inhalation power or not.[(14)] A peak inspiratory flow rate (PIFR) of at least 1Liter/second is required for the dry powder inhaler (DPI) devise other wise an alternative meter dose device with a spacer or a nebulizer may be recommended and this information is readily available on the descending part of a flow volume loop of the spirometry tracing Figure 1.. The group 'C' (restrictive pattern) had <70% FVC value with normal or supra-normal FEV1/FVC ratio suggestive of restrictive disease pattern and the examples may be ILD, sarcoidosis, neuromuscular disorder, etc., and if these cases clinically have brochospasm, then they may require more inhalation power to expand a fibrosed lung.

Future Prospects

The most frequently observed abnormality on spirometry is diminished air flow or obstructive ailments, which require a standard force expiratory maneuver; however, multiple attempts may be required due to failure to get a satisfactory, valid recording. The older persons, children below the age of 8 years, and seriously ill patients, etc., cannot follow and perform spirometry. Impulse oscillometry claims to be more sensitive than spirometry in the early detection of chronic obstructive pulmonary disease [(15)]. Kouri Andrew further mentioned another newer technology as fraction of exhaled nitric oxide (FENO). Both FENO and the oscillometry do not require any manoeuvres, and the performer has to simply breath as usual and quietly inside the machine. FENO is handy, cheaper, and likely to become more popular.[(15)]

Conclusion

Spirometry continues to be a very important component in the diagnostic armamentarium in the management of respiratory disease. The ready availability, ease of procedure and patient compliance make it a popular test. However, the correct technique of procedure and proper interpretation of the report goes a long way in the proper management of the patient.

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