Peak Expiratory Flow With or Without a Brief Postinspiratory Pause*

Tariq Omar, MD; Husain Alawadhi, MD; Ayman O. Soubani, MD, FCCP; and George E. Tzelepis, MD, FCCP

**Background:** The duration of postinspiratory pause prior to forced expiration may significantly influence the peak expiratory flow (PEF) measured during maximal forceful expirations. In comparison with maneuvers without a postinspiratory pause, maneuvers with 4 to 6-s pause at total lung capacity (TLC) result in decreased PEF values. The extent to which brief pauses (< 2 s) similarly affect PEF values is unknown.

**Methods:** Thirty-six healthy volunteers (mean ± SD age, 35 ± 8 years; 18 men) performed a series of maximal forceful expirations with two different types of maneuvers. One maneuver (NP) included no inspiratory pause at TLC prior to forced expiration, whereas the second (P) included a brief pause (≤ 2 s). The speed of inhalation to TLC was rapid and similar for both maneuvers. The highest PEF for each maneuver was used for analysis.

**Results:** The maximal PEF did not differ (p > 0.05) between the P and NP maneuvers (7.78 ± 1.45 vs 7.83 ± 1.45 L/s, respectively). Comparison of the intermaneuver differences showed a bias of 0.05 L/s and 95% confidence interval in the range of −0.9 to 1.0 L/s.

**Conclusions:** Forceful expiratory maneuvers with or without postinspiratory pauses of ≤ 2 s produce identical maximal PEF values and, therefore, can be used interchangeably for the spirometric measurement of PEF in healthy subjects.

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**Key words:** peak expiratory flow; postinspiratory pause; pulmonary function testing; spirometry

**Abbreviations:** NP = maneuver type with no inspiratory pause

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Peak expiratory flow (PEF), the maximal flow that can be achieved during a forced expiration at total lung capacity (TLC), is an important parameter that is used to monitor airway obstruction. PEF is determined in large part by the lung volume, lung elastic recoil, and muscular effort. Studies in healthy volunteers and patients with lung diseases showed that the type of inspiratory maneuver preceding forceful expiration could affect the magnitude of PEF. The values of PEF are significantly higher if the FVC maneuver is preceded by fast inspiration without a postinspiratory pause than when it is preceded by a slow inspiration with a 4 to 6-s postinspiratory pause. This dependence of PEF on the length of postinspiratory duration is best explained on the basis of the lung elastic recoil pressure, which is time-dependent, and, therefore, the longer pause will result in lower effective lung elastic recoil pressure prior to expiration and, thus, lower PEF. An additional mechanism that could also lead to greater PEF values with the fast inspirations is related to enhancements of expiratory muscle force output because of the stretch-shorten cycle.

Currently, the published guidelines for measuring PEF provide no precise recommendations about the speed of inspiration preceding expiration and the appropriate duration of the postinspiratory pause. Although long postinspiratory pauses (i.e., > 3 s) are generally not used, pauses of ≤ 2 s are often allowed prior to expiration in most pulmonary laboratories. The extent to which these brief pauses may similarly affect measurements of PEF is unknown.

This study was undertaken in a group of healthy volunteers with the objective to compare PEF values obtained spirometrically during FVC maneuvers that included an inspiratory pause at TLC prior to forceful expiration (P) [about 2 s] with PEF measured with maneuvers that included no inspiratory pause at TLC prior to forceful expiration (NP). The speed of inspiration to TLC prior to forced expiration was similar (about 1 to 2 s) for both maneuvers.

**Materials and Methods**

Thirty-six healthy volunteers (mean age, 36 ± 8; 18 men) participated in the study. All of the subjects were nonsmokers; had no history of asthma, cough, or recent respiratory infection; and were not taking medications during the study. The subjects were naïve to the purpose of the study and all but two had never performed spirometry before. The research was approved by the institutional ethics committee, and informed consent was obtained from all of the subjects.

Respiratory flow was measured with a pneumotachograph...
The subjects were tested in two sessions, approximately 2 to 3 weeks apart. In each session, they performed a series of forced expirations using two different types of maneuvers. These two types of maneuvers were the NP maneuver and the P maneuver. With the NP maneuver, the subjects inhaled rapidly to TLC and immediately performed the forced expiration, whereas with the P maneuver the subjects inhaled rapidly to TLC and after a brief pause (about 2 s) performed the forceful expiration. All of the subjects were instructed to exhale as fast and as hard as possible, focusing on the initial split seconds of expiration. The neck was kept in a neutral position in order to reduce PEF variability related to the tracheal shape.11 During these maneuvers, all of the subjects were coached by the same operator.

All of the subjects initially practiced both expiratory maneuvers. Following familiarization with the two types of maneuvers, they performed a total of eight forced expirations, four with each type of maneuver in an alternate fashion. Ample time was allowed for rest between trials. Of the 36 subjects who completed measurements in the first session, 33 returned to the laboratory for the second session of measurements. With these two sessions, the subjects generated a series of individual forced expirations. For each session, the largest PEF and the average for each maneuver and subject were chosen for analysis.

Data are presented as mean (± SD). A paired t test was used to compare the intermaneuver differences in PEF. The agreement between the two maneuvers was analyzed with the method of Bland and Altman,12 in which agreement between the two maneuvers was expressed in a diagram showing the differences between maneuvers plotted against the mean of the two. All of the statistical analyses were performed with computer software (Analyze-It with Microsoft Excel for Windows; Analyze-It Software Ltd; Leeds, UK).

RESULTS

Figure 1 shows the typical volume and flow tracings with each expiratory maneuver. There were no differences in the best PEF or average PEF between the two maneuvers (Table 1). With the P maneuver, the best PEF was achieved with the first three trials in 78% of the individual blows, whereas with the NP, the best PEF was achieved with the first three trials in 75% of the individual blows. In 52% of the individual blows, the best PEF was achieved with the NP maneuver and in 45% of the individual blows with the P maneuver (p > 0.05 [x² test]).

Figure 2 shows the Bland and Altman12 analysis for the intermaneuver differences in PEF. The bias was 0.05 L/s with 95% confidence intervals from −0.069 to 0.171 L/s. The lower and upper 95% limits of agreement were −0.929 and 1.031 L/s, respectively.

Table 1—Data Obtained With the Two Maneuvers*

<table>
<thead>
<tr>
<th>Variables</th>
<th>P Maneuver</th>
<th>NP Maneuver</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEF, L/s</td>
<td>7.78 ± 1.45</td>
<td>7.83 ± 1.45</td>
<td>NS</td>
</tr>
<tr>
<td>Average</td>
<td>7.44 ± 1.43</td>
<td>7.48 ± 1.37</td>
<td>NS</td>
</tr>
<tr>
<td>Pause, s</td>
<td>1.63 ± 0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vinsp, L/s</td>
<td>4.03 ± 1.3</td>
<td>4.40 ± 1.4</td>
<td>0.002</td>
</tr>
<tr>
<td>FEV₁ best, L</td>
<td>3.16 ± 0.62</td>
<td>3.19 ± 0.62</td>
<td>NS</td>
</tr>
</tbody>
</table>

*Values given as mean ± SD, unless otherwise indicated. NS = not significant; Vinsp = inspiratory flow.

The two maneuvers differed only in the duration of inspiration, with the NP maneuver containing essentially no inspiratory pause. The subjects were asked to inhale rapidly to TLC, but no other instructions were given about the vigor of inspiration. With regard to breathhold at TLC, the subjects were simply instructed to pause until they heard the cue for forceful expiration.

Agreement of the maneuvers was analyzed with the method by Bland and Altman,12 which showed that the mean intermaneuver difference (bias) was negligible. Also, the differences appeared to be uniform through the range of PEF measurements following a normal distribution (Fig 2, right). The 95% limits of agreement, however, ranged from −0.9 to 1.0 L/s. This range of dispersion is relatively large and is most likely related to the intraindividual variability of PEF.7,13–15

In several previous studies, fast inspiratory maneuvers with no breathhold were associated with greater PEF values in healthy volunteers,2,3,7 as well as patients with asthma,7,16 COPD,3 cystic fibrosis,4 or restrictive diseases6 when compared with maneuvers that included a breathhold of about 4 to 6 s. In certain patients, particularly COPD and cystic fibrosis,4,5 the differences in PEF and other spirometric parameters were much greater, probably reflecting the lung viscoelastic properties of these patients. In view of these findings, several authors2,4–7...

Figure 1. Representative tracings of flow and lung volume during forced expirations in a volunteer with two different maneuvers. Note that with the P maneuver there is about a 2-s breathhold at TLC prior to forceful expiration, whereas with the NP maneuver there is essentially no postinspiratory pause.
emphasized the need to standardize the duration and type of inspiration preceding forceful expiration. They argued that rapid inspiratory efforts to TLC followed immediately by forceful expiration should be used for the spirometric measurements of FVC. In the absence of data, the American Thoracic Society and the European Respiratory Society in their most recent statements provided no detailed recommendations about the duration of inspiration. Although the American Thoracic Society guidelines recommend avoidance of excessive pauses at TLC, the European Respiratory Society guidelines suggest a maximum postinspiratory pause of about 2 s.

The speed of inspiration may influence the magnitude of PEF measured during the subsequent expiration through its effects on the elastic recoil pressure of the lungs and chest wall and through its effects on the respiratory muscle force. Fast inspirations produce greater increases in the elastic recoil of the lung and chest wall and, therefore, result in greater PEF values. Fast inspirations can also enhance expiratory muscle pressure during the subsequent expiration via the stretch-shorten cycle. With fast inspirations, the expiratory muscles are actively stretched and are then shortened during the subsequent expiration. As in peripheral muscles, the transition from an activated stretched muscle (eccentric contraction) to one that is now shortening can augment respiratory muscle force output. In some studies, forceful inspirations that were immediately followed by forced expirations produced greater increases in the expiratory pressures (by approximately 10 to 15%) when compared with maneuvers characterized by slow inspirations and postinspiratory pauses at TLC. To the extent that PEF is flow-limited in most healthy subjects, greater expiratory pressures in the setting of an optimally performed forced expiratory maneuver will not result in an additional increase in PEF.

The length of postinspiratory pause may neutralize the inspiratory maneuver effects on PEF. A breathhold at TLC allows stress relaxation in both the airway wall and lung parenchyma to occur and, thus, increases the airway compliance and decreases the effective elastic recoil pressure. In previous studies, long pauses (≥ 10) were invariably associated with decreases in PEF. Pauses of about 4 to 6 s were also associated with decreases in PEF in the range of 6 to 13%, especially when comparisons were made between maneuvers with fast inspirations and those with slow inspirations. For maneuvers in which inspiratory speed was relatively slow, the effect of a breathhold on PEF was less pronounced in healthy volunteers. As suggested by studies in peripheral muscles, long postinspiratory pauses may also offset the enhancement of expiratory muscle force related to the stretch-shorten cycle.

There may be several explanations for the lack of differences in PEF between the two maneuvers. First, intervals of ≤ 2 s are probably too short for significant changes in the airway wall and the lung parenchyma to take place, especially when subjects do not relax their respiratory muscles during the breathhold. In healthy volunteers, the decreases in PEF with longer pauses (i.e., 4 to 6 s) were found to be in the range of about 6 to 8% and occurred in some but not all of the subjects. Therefore, it is highly likely that the changes in the PEF induced by periods of 2 s are relatively small and perhaps smaller than the changes related to the PEF variability.

A study in healthy volunteers found that maneuvers with a postinspiratory pause of 2 s at TLC decreased PEF by about 10% when compared with maneuvers without a pause. However, this study is not directly comparable to our study because of methodologic differences; the study included only five volunteers in whom the analysis of intermaneuver differences in PEF was based, not on the highest PEF, but on matched effort as assessed by the...
esophageal pressure. Furthermore, unlike our study, the subjects were asked to relax the respiratory muscles during breathhold, which most likely caused a relatively greater increase in the compliance of the airway wall.

The inspiratory flow was slightly greater with the NP maneuver, perhaps because of the overall faster character of the NP maneuver in comparison with the P maneuver. However, this difference in inspiratory speed is very unlikely to have systematically biased our data for several reasons. First, the 10% difference in inspiratory speed between the two types of maneuvers is relatively small. In previous studies in which inspiratory speed with the NP maneuvers accounted for the intermaneuver differences in PEF, the inspiratory flow was several-fold greater than that of the pause maneuvers.2–4,7 Furthermore, to the extent that NP maneuvers are more likely to produce greater PEF, if there was any inspiratory speed-related bias, this would have led to greater PEF values with the NP than with the P maneuver. However, the finding of similar PEF values for the two types of maneuvers argues against it. In general, the inspiratory speed was in the same range as that used in previous studies2 examining the effect of fast inspirations on PEF.

Our data apply to healthy volunteers and may not be extrapolated to patients without caution. In COPD patients, fast maneuvers with no inspiratory pause produced relatively greater increases in PEF than maneuvers incorporating postinspiratory pauses.5 This may be related to several factors including time-constant inequality within the lung in these patients. Because maneuvers with a brief postinspiratory pause allow coaching in a stepwise manner, they might be easier to perform in the pulmonary function laboratory, especially by the poorly cooperative patient. In conclusion, we found that forceful inspiratory maneuvers with or without postinspiratory pauses of ≥2 s produce identical maximal PEF values and, therefore, can be used interchangeably for the spirometric measurement of PEF in healthy subjects.

REFERENCES

α1-Antitrypsin and Neutrophil Elastase Imbalance and Lung Cancer Risk*

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Objective: Imbalance between α1-antitrypsin and neutrophil elastase is an underlying cause of lung