

## The Inspiratory Flow-Volume Curve: The Neglected Child of Pulmonary Diagnostics

I don't get no respect!

—Rodney Dangerfield

The physiology underlying inspiratory flow has been the subject of study for a long time. In the late 1950s, Hyatt et al did seminal investigations of the pressure, flow, and volume characteristics of the lung.<sup>1</sup> In those early days the primary interest in flow-volume curves centered on expiratory flow, what controlled it, and how it was limited in various obstructive lung diseases.<sup>2</sup> Even in the oldest reports, inspiratory flow (including maximum inspiratory flow) was included (see Figs. 9 and 12 in Hyatt and Fry's 1960 report).<sup>2</sup> However, inspiratory flow and the pathophysiology of reduced inspiratory flow have generally been given short shrift. In a 1973 review of flow-volume curves,<sup>3</sup> Hyatt and Black allocated just 2 short sentences to the usefulness of the flow-volume loop in the diagnosis of large airway lesions.

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The past 30 years have seen many reports that described flow-volume patterns characteristic of specific upper and/or large airway abnormalities. For the most part those studies were observational and restricted to relatively small populations. And though the maximum expiratory flow-volume curve (the expiratory limb of the curve) is highly regarded as displaying a wealth of information about airway obstruction in its various manifestations, the inspiratory limb of the loop doesn't get the same attention. Flattening of the inspiratory limb associated with vocal cord dysfunction<sup>4</sup> and "saw-toothing" associated with obstructive sleep apnea<sup>5</sup> are 2 widely recognized patterns in which the other limb assists in making a diagnosis. But, despite those associations, inspiratory flow patterns remain something of an afterthought in spirometric interpretation.

The fact that the maximum inspiratory flow is effort-dependent may contribute to its status as a "second-class citizen" in pulmonary diagnostics. The utility of the flow-volume loop to graphically convey information concerning air flow into and out of the lungs seems compromised when a clinician has to look at multiple tracings to separate submaximal effort from real abnormal physiology. That there are few widely used quantitative variables to

describe maximum inspiratory flow contributes to the dilemma. The ratio of the forced expiratory flow at 50% of the expired vital capacity to the forced inspiratory flow at 50% of the inspired vital capacity ( $FEF_{50\%}/FIF_{50\%}$ ) is commonly used to quantify what the flow-volume loops shows us, but it suffers from the same shortcomings as most ratios: the absolute values of the numerator and denominator need to be considered as well.<sup>6</sup>

Spirometry standardization has also been a continuing endeavor for the last 30 years. Flow-volume loops, and inspiratory flow in particular, have received minimal attention. Only in the most recent spirometry guidelines are criteria for acceptable flow-volume loops even mentioned.<sup>7</sup> These criteria primarily require that the flow-volume curves (either expiratory or inspiratory) are repeatable when superimposed, to distinguish between poor effort and large/upper-airway obstruction. A similar situation had existed in regard to the interpretation of maximum inspiratory and expiratory flows. The 1991 American Thoracic Society recommendations made no mention of flow-volume loop interpretation.<sup>8</sup> The 2005 interpretive guidelines discuss variable and fixed intrathoracic and extrathoracic obstruction, and provide representative flow-volume loops,<sup>9</sup> but, oddly, those guidelines recommend the ratio of the maximum inspiratory flow at 50% of the vital capacity to the maximum expiratory flow at 50% of the vital capacity ( $MIF_{50\%}/MEF_{50\%}$ ), rather than the more common  $FEF_{50\%}/FIF_{50\%}$ , for categorizing the type of obstruction.

This issue of *RESPIRATORY CARE* contains 3 papers that deal with flow-volume loops in general, and inspiratory flow in particular, from slightly different viewpoints. The paper by Sterner et al<sup>10</sup> retrospectively reviews flow-volume loops from a large number of subjects with essentially normal spirometry, to seek out abnormal inspiratory flow patterns. The intent was to determine if evaluation of the airway was performed and whether any large/upper-airway obstruction was found. Sterner et al document some of the difficulties encountered when pattern-recognition is the tool used to make the diagnosis. Patterns included "absent," "truncated," and "flattened." They also sought to classify the repeatability of the patterns based on a comparison of 3 recorded loops. Nonrepeatability might seem to be a nonissue for an effort-dependent test, but the study considered the possibility that variability in the inspiratory flow pattern might be diagnostic (as in vocal cord dysfunction).

Perhaps the most important finding by Sterner et al<sup>10</sup> was that almost 50% of the “abnormal” inspiratory loops were the result of poor effort, but were chosen because the software selected the flow-volume loop with the largest sum of forced vital capacity plus forced expiratory volume in the first second, without regard for the inspiratory effort that happened to accompany it. Sterner et al found that even when the inspiratory limb was repeatable and abnormal, only a small percentage of the subjects were evaluated further to rule out large/upper-airway obstruction. Interestingly, the study detected 8 subjects with vocal cord dysfunction, none of whom had consistently abnormal inspiratory flow. As might be expected, recalculation of the  $FEF_{50\%}/FIF_{50\%}$  with the inspiratory loop with the highest flow (rather than the one that accompanied the best expiratory effort) made a significant difference.

Another study in this issue, by Watson and co-workers,<sup>11</sup> looked at whether flow-volume curves can detect vocal cord dysfunction. They studied a large number of subjects who had laryngoscopically determined vocal cord dysfunction, and they identified a “new” variable that seems to be related to vocal cord dysfunction: the ratio of the forced inspiratory flow at 25% of the inspired volume to the forced inspiratory flow at 75% of the inspired volume ( $FIF_{25\%}/FIF_{75\%}$ ) taken from the best forced-vital-capacity effort. However, when their data were analyzed with the best inspiratory loop data, no spirometric variables were predictive of vocal cord dysfunction.

The third paper related to flow-volume loops in this issue, from Modrykamien et al<sup>12</sup> at the Cleveland Clinic, takes a broader approach in trying to determine what spirometric variables identify upper-airway obstruction. They included both visual and quantitative evaluation of flow-volume loops, including variables based on inspiratory flow. With evidence from bronchoscopy, computed tomography, and laryngoscopy they found that neither visual criteria nor individual quantitative measurements that suggested upper-airway obstruction were predictive for identifying abnormalities. A combination of the 4 quantitative criteria, assessed with receiver operating characteristic curves, appears to be slightly more sensitive in detecting upper-airway obstruction. Only 7.5% of the subjects in that study had upper-airway obstruction; and though a few had vocal cord paralysis, none had vocal cord dysfunction.

What findings from these 3 papers<sup>10-12</sup> should concern pulmonary function technologists and clinicians who rou-

tinely perform spirometry that includes flow-volume loops? There are few recommendations from professional organizations regarding acceptability and repeatability of the maximum inspiratory effort, so practitioners need to be alert and use common sense when evaluating inspiratory maneuvers. Superimposing loops is an easy method for detecting important differences in flow, which are commonly the result of differences in patient effort. Carefully evaluate the  $FEF_{50\%}/FIF_{50\%}$  and pay attention to the absolute flows from which the ratio is derived. Check the software being used to determine how the “best” flow-volume curve is selected. Is it selected just by the effort that accompanied the best forced expiration? Most spirometers default to that value but allow the user to mix and match inspiratory and expiratory flow curves. Perhaps most importantly, all of the inspiratory loops should be reviewed in the context of the clinical question(s) being asked, keeping in mind that variability may be an important finding.

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The author declares no conflicts of interest.

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