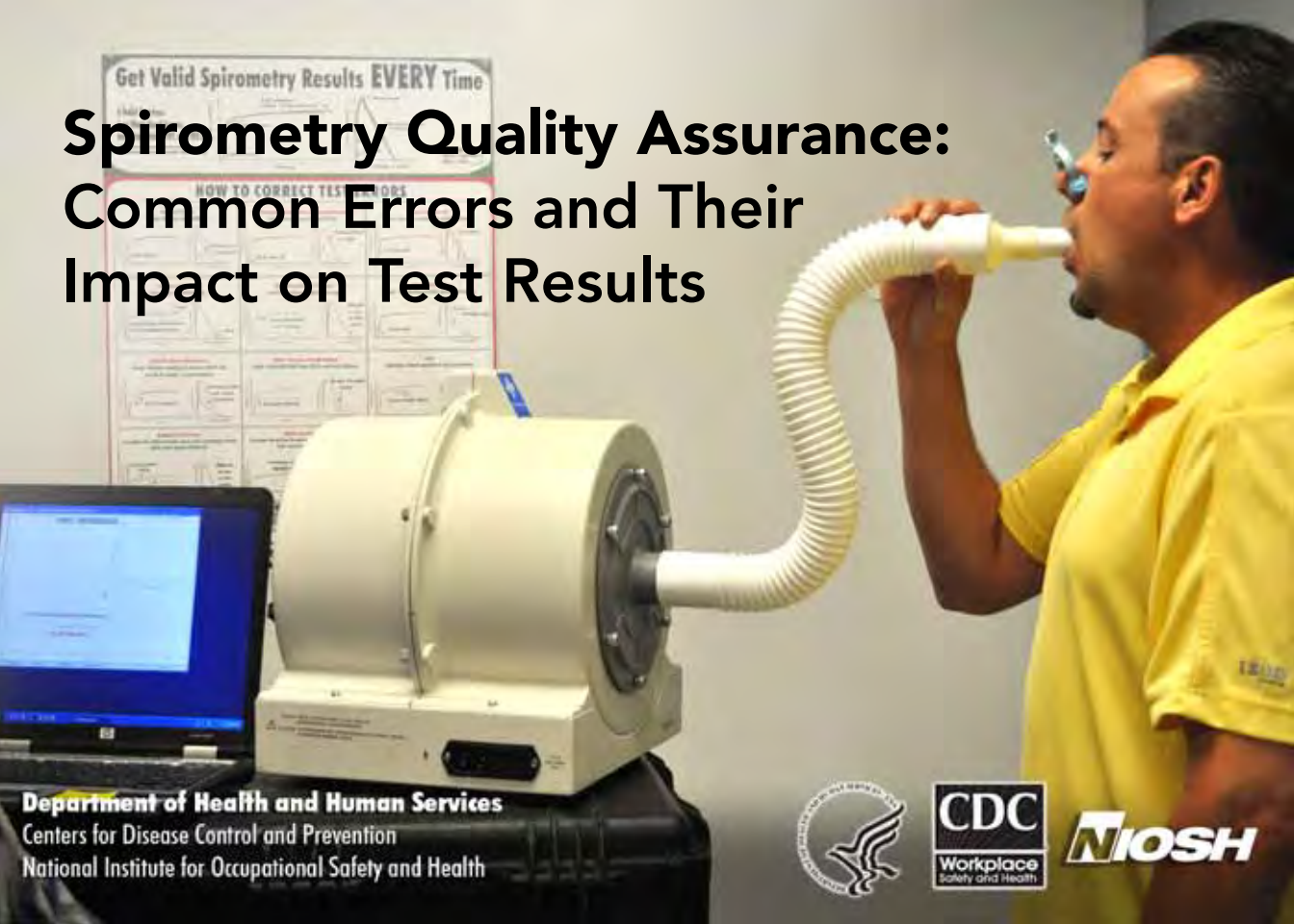

Spirometry Quality Assurance: Common Errors and Their Impact on Test Results

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Spirometry Quality Assurance: Common Errors and Their Impact on Test Results

Spirometry is the most common pulmonary function test (PFT) and it plays a central role in occupational respiratory disease surveillance programs. Accurate spirometry testing, interpretation, and follow-up are critical to effective screening and surveillance of workers exposed to respiratory hazards and to the management of patients in the clinical setting.

Spirometry quality assurance includes examination of test values and evaluation of both the volume-time and flow-volume curves for evidence of technical errors. Technically poor spirometry may have little value and may even provide misleading information. When erroneous curves are detected, additional maneuvers are often needed. During testing, technicians should attempt to record a **valid test**, which is composed of at least 3 acceptable maneuvers with consistent ("repeatable") results for both FVC and FEV_1. Achieving repeatability during testing means that the difference between the largest and second largest values for both FVC and for FEV_1 are within 0 .15 l (150 ml). Additional maneuvers can be attempted, up to a maximum of 8, to meet these criteria for a valid test. Even tests that have 3 acceptable maneuvers of which at least 2 are repeatable may not represent an individual's maximum effort. Ideally, there should be 3 maximal effort curves with the same size and shape.

This guide depicts common testing errors and shows how these errors can impact spirometry results. However, health professionals must bear in mind that, though the goal during testing is to obtain a valid test as described above, results from invalid tests may sometimes provide

information that can be used to infer respiratory health status. In 1994, the American Thoracic Society* stated that tests should not be interpreted if fewer than 2 acceptable curves were recorded, reflecting the fact that useful information may be present even in tests that are not optimal. In fact, some medical conditions prevent workers and other test subjects from successfully recording valid tests, in spite of the best efforts of the technician and the subject to produce such results. Clinical judgment should be used to determine whether curves are so unacceptable that they would lead to a misinterpretation of respiratory health.

The first figure represents a valid normal spirometry test including 3 curves, each produced by a separate expiratory maneuver (trial). All subsequent figures with examples of testing errors show one acceptable trial (green – solid line) together with one or more trials with the error (red – dashed line) for comparison. If more than one red trial is presented, then the test results from the trial with the largest values are reported. Only test results that are impacted by the specific error will be shown in the tables for these examples.

In the following figures, FEV_1 is indicated by a vertical mark 1 second after the start of the volume-time curves, and arrows are used to emphasize key features of the curves in each example.

*American Thoracic Society. Standardization of Spirometry: 1994 Update. Am J Respir Crit Care Med 1995:152;1107-1136.

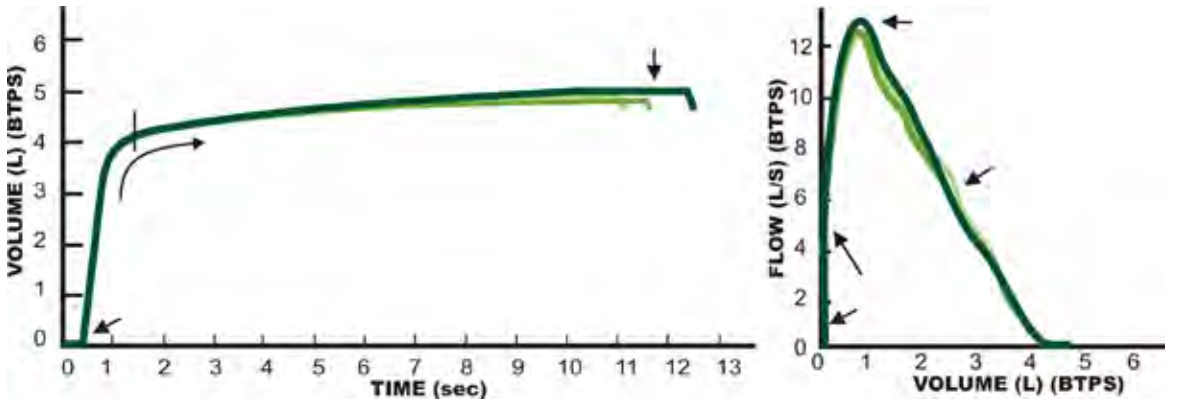
List of Abbreviations:

BTPS = body temperature and pressure saturated
FEV_1 = forced expiratory volume in one second
FEV_1/FVC = ratio of forced expiratory volume in one second compared to the total volume of air exhaled, expressed as a percent
FVC = forced vital capacity
PEF = peak expiratory flow
% Pred = percent of predicted value
LLN = lower limit of normal
Vext = extrapolated volume

Valid Normal Test

Trial	FVC (L)	FEV_1 (L)	PEF (L/sec)
1	4.81	4.09	12.1
2	4.74	4.07	12.0
3	**4.87**	**4.14**	**12.5**
Repeatability	0.06	0.05	

4.87-4.81 = 0.06 4.14-4.09 = 0.05



A valid test has at least 3 acceptable trials and both the FVC and FEV_1 are repeatable [i.e., the two highest values from acceptable maneuvers are within 0.15 L (150 ml)].

The volume-time curve (left) shows the time course of exhalation, starting from the baseline (i.e., zero) volume, rising sharply, and then gradually slowing until a 1-second FVC plateau is drawn, indicating the end of exhalation. The volume-time curve allows practitioners to evaluate the completeness of the end of the test. The American Thoracic Society* recommends that subjects try to exhale for at least 6 seconds; however, young healthy adults may empty their lungs before 6 seconds. No trial should be deleted on the basis of exhalation time as the FEV_1 may still be valid. A volume-time curve that does not plateau before 15 seconds despite maximal effort by the subject may indicate "obstructive impairment." Also, it may be difficult to reach a plateau on the volume-time curve for some subjects who cannot sustain their expiration. This may happen in obese subjects or those with some underlying lung diseases. The flow-volume curve (right) emphasizes patient effort and shows detailed information at the beginning of the test. It is characterized by: 1) an immediate vertical rise, 2) a sharp peak, and 3) a fairly smooth descent that returns to zero flow.

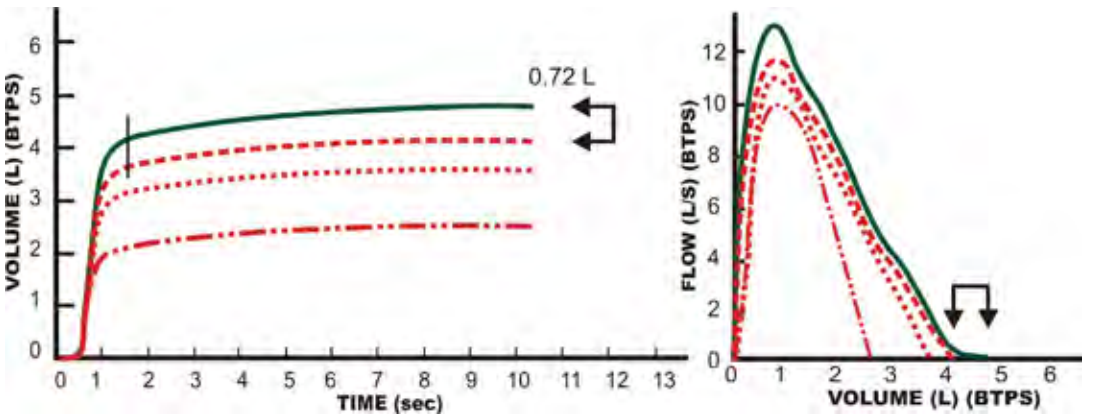
In this guide, the first second of exhalation is designated by a black vertical line crossing the volume-time curve. Not all spirometry displays have a 1-second marker.

*American Thoracic Society/European Respiratory Society. Standardization of spirometry. Eur Respir J 2005:26:319-338.

Error #1: Sub-maximal Inhalation

	FVC (L)	FVC % Pred	FVC LLN (L)	FEV_1 (L)	FEV_1 % Pred	FEV_1 LLN (L)
Good Effort	4.90	96	4.17	4.17	103	3.29
Error	4.18	82	4.17	3.60	88	3.29

4.90-4.18 = 0.72



Problem: Sub-maximal inhalation causes underreporting of true spirometry results. An incomplete inhalation is a frequent and serious problem that occurs in spirometry testing.

Identification: Lack of full inspiration can be seen as a gap between the FVC plateaus on multiple volume-time curves (left) and also as a space between the ending points of multiple flow-volume curves (right). The shape of both types of curves will be similar, but the curves will vary in size. Flow-volume curves with sharp peaks indicate that the efforts have good initial blasts, but the difference in maximal airflow (PEF) may be caused by lower elastic recoil associated with less "stretching" of the lung with smaller volumes.

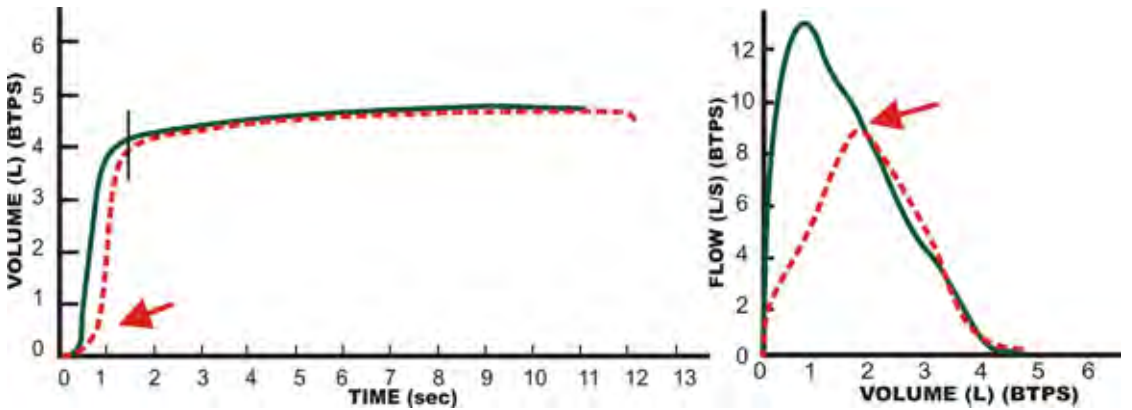
Test Result Implications: Falsely reduced FVC can be misinterpreted as indicating a "restrictive impairment." Results from tests with varying inspirations may fail to achieve the repeatability needed for a "valid" test. Although in this example we do not have a repeatable test, a test interpretation of "normal" is still valid. An incomplete inhalation results in falsely low values which may be below the LLN. However, in this example, the FVC and FEV_1 values are above the LLN and the results appear "normal."

Solution: Coach the subject to FILL THEIR LUNGS, taking the deepest possible breath.

Spirometer Error Message: "FVC variable", "FEV_1 variable", or "Take a deeper breath."

Error #2: Excessive Extrapolated Volume

	FVC (L)	FEV_1 (L)	FEV_1 % Pred	PEF (L/sec)	Vext (L)	Vext (%)
Good Effort	4.79	4.12	86	12.2	0.12	2.5
Error	4.78	3.95	82	8.5	0.55	11.5



Problem: A slight hesitation in blowing out before the initial blast affects most spirometry test results early in the maneuver. A maneuver showing this error must not be used to measure FEV_1 but it may be used to validate the FVC if it is consistent with other acceptable, but less than perfect curves.

Identification: Since hesitation occurs early in the test, it is most easily seen in the flow-volume curve (right), which has its peak flow displaced to the right. The spirometer makes a measurement called "extrapolated volume" (Vext) to determine whether a hesitation is excessive. The extrapolated volume is unacceptable if it exceeds 0.15 liters or 5% of the FVC, whichever is larger.

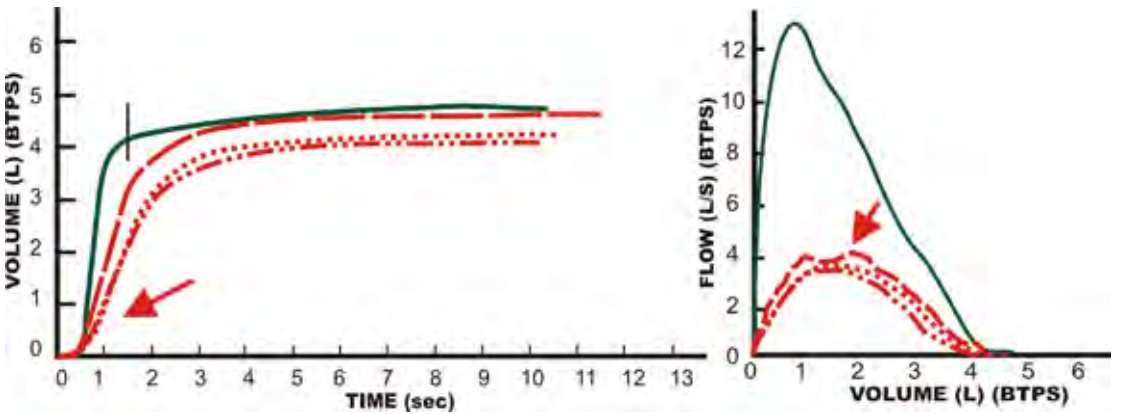
Test Result Implications: Large extrapolated volume can falsely elevates the FEV_1, though occasionally the FEV_1 may be reduced.

Solution: Coach the subject to blast FASTER or IMMEDIATELY.

Spirometer Error Messages: Most spirometers label this error with "Hesitation," "Large extrapolated volume," or "Start faster."

Error #3: Sub-maximal Blast

	FVC (L)	FEV_1 (L)	FEV_1 % Pred	PEF (L/sec)
Good Effort	4.69	4.08	86	12.6
Error	4.57	3.36	71	4.1



Problem: A poor initial blast affects spirometry measurements made early in the maneuver.

Identification: This problem is most clearly seen on the flow-volume curve (right). The peak on the curve is reduced, indicating insufficient subject effort — the weaker the blast, the lower the peak (PEF). On the volume time curve (left), a weak blast prevents the curve from rising sharply from the volume baseline.

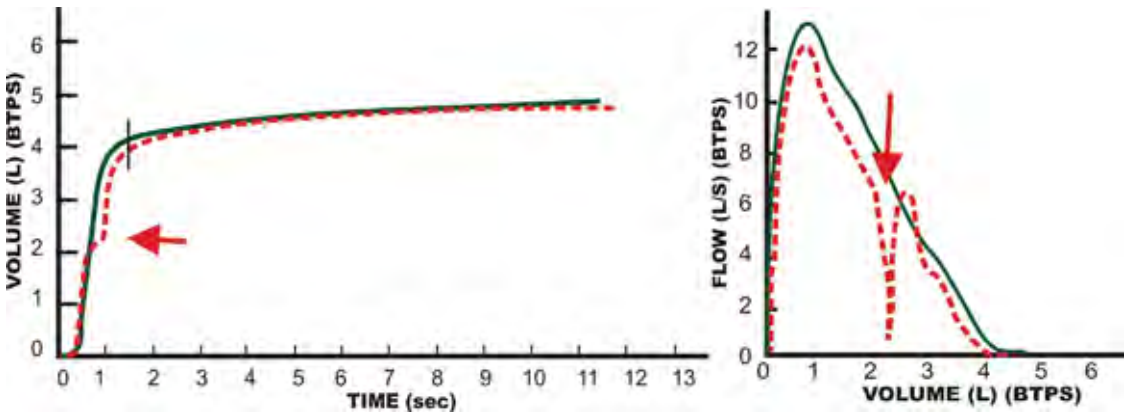
Test Result Implications: A curve with low peak flow will have falsely reduced FEV_1 and FEV_1/FVC ratio that may be misinterpreted as "obstructive impairment" if other good curves are not available. A repeatable test (both the FVC and FEV_1) may occur with sub-maximal effort. In this example the FVC is repeatable but the FEV_1 is not.

Solution: Coach the subject to blast the air out HARDER.

Spirometer Error Messages: Spirometers may not label these curves as errors, so health professionals must recognize these patterns.

Error #4: Cough in First Second

	FEV_1 (L)	FEV_1 % Pred
Good Effort	4.12	88
Error	3.96	84



Problem: Coughing in the first second may affect the FEV_1 measurement, while coughing after the first second will not affect the FVC measurement unless the subject stops blowing prematurely. A maneuver showing this error must not be used to measure FEV_1 but it may be used to validate the FVC if it is consistent with other acceptable, but less than perfect curves.

Identification: Cough is most clearly seen as a jagged interruption in the flow-volume curve (right). Although this example has one cough, often there are multiple coughs in a single maneuver. Cough is more difficult to see on the volume-time curve.

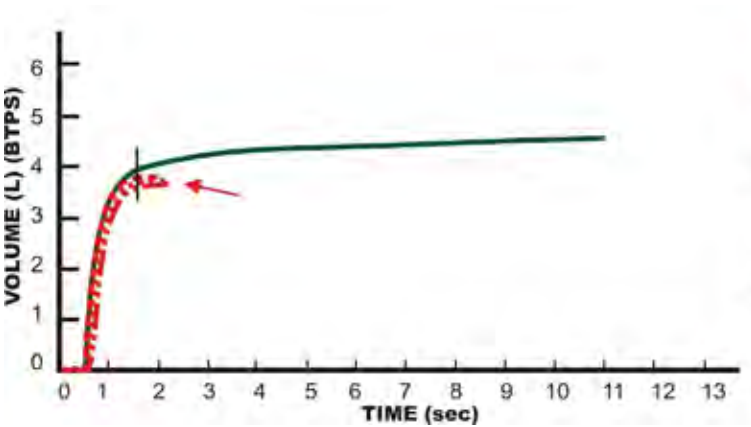
Test Result Implications: A cough can cause either a falsely reduced or falsely elevated FEV_1, depending on the strength of the cough. However, a cough is difficult to define and its appearance on the display is very instrument-dependent. Significant coughing may cause a falsely reduced FVC. In any case, because the FEV_1/FVC ratio may be inaccurate, the maneuver is unacceptable.

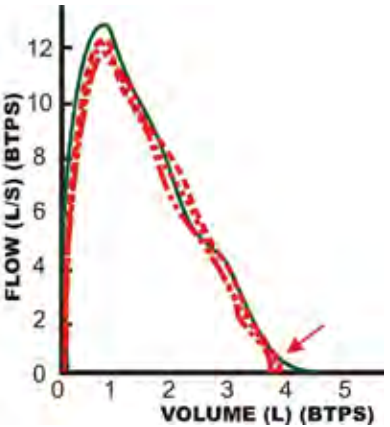
Solution: Coughing is difficult to manage. Offering a drink of water before the maneuver may help.

Spirometer Error Message: Some spirometers label this error with "Cough."

Error #5: Early Termination

	FVC (L)	FVC % Pred	FEV_1 (L)	FEV_1 % Pred	FEV_1/FVC%
Good Effort	4.54	83	3.91	87	86
Error	3.81	67	3.76	84	98





Problem: Subjects who do not completely exhale have falsely reported spirometry results.

Identification: Early termination is most clearly seen as a lack of plateau on the volume-time curve (left). Most healthy adults can exhale for >6 seconds, and more time is required to reach the plateau as subjects age or develop airways obstruction. However, many young healthy subjects exhale to their plateaus within 3 to 5 seconds and these are valid tests. If the maneuver is terminated early enough, this error can also be seen as a sharp drop to zero flow on the flow-volume curve (right).

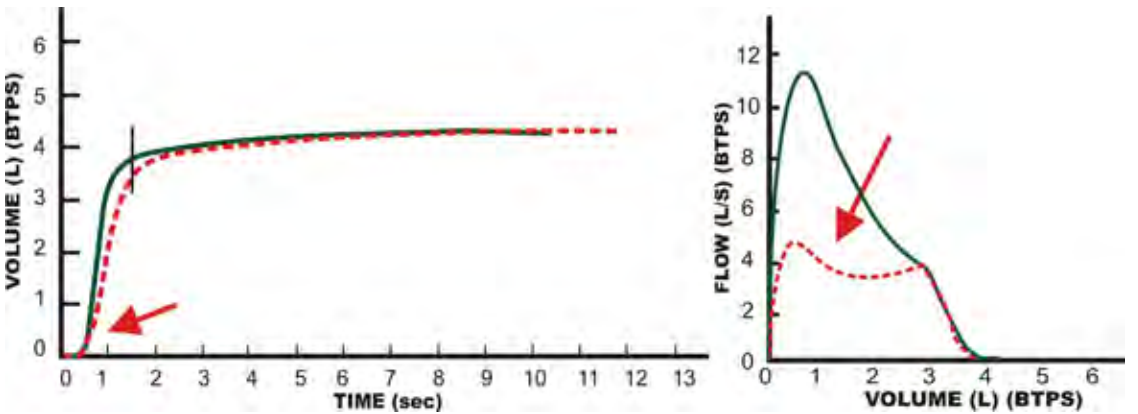
Test Result Implications: The falsely reduced FVC may be misinterpreted as indicating a "restrictive impairment." The falsely increased FEV_1/FVC ratio may cause a true "obstructive impairment" to be missed. So, an interpretation of "no restrictive impairment" may be accurate if the FVC is above the LLN. However, since the FEV_1/FVC ratio may not be valid, one cannot rule out an obstructive pattern.

Solution: Coach the subject to KEEP BLOWING until told to stop.

Spirometer Error Message: Spirometers may label this error as "Early termination" or "Keep blowing". Other spirometers may not label these curves as errors, so health professionals must recognize these patterns.

Error #6: Variable Effort

	FEV_1 (L)	FEV_1 % Pred	FEV_1/FVC%	PEF (L/sec)
Good Effort	3.73	86	88	10.8
Error	3.49	80	82	4.8



Problem: Exhaled airflow varies substantially if effort is variable, particularly during the first 2-3 seconds of the maneuver.

Identification: While coughs are usually seen as jagged interruptions in the flow-volume curve, variable effort is often seen as a dip in the flow-volume curve (right). The more variable the effort, the larger the dip on the flow-volume curve.

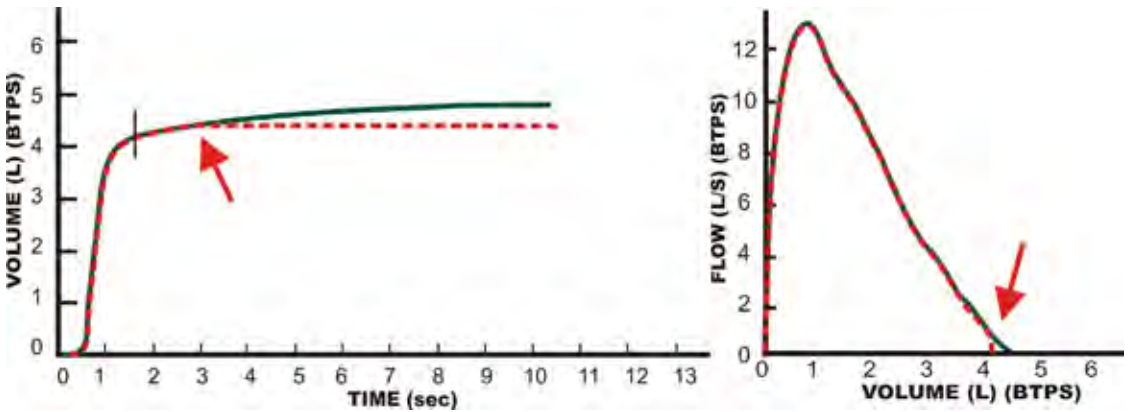
Test Result Implications: The falsely reduced FEV_1 and FEV_1/FVC ratio may be misinterpreted as indicating an "obstructive impairment." However, the shape of the flow-volume curve and the reduced PEF indicate that the low values are caused by poor effort.

Solution: Coach the subject to blast one breath out HARD and FAST, and KEEP BLOWING out.

Spirometer Error Message: Many spirometers do not label this error, so health professionals must recognize these patterns.

Error #7: Cessation of Airflow – Glottis Closure or Breath Holding

	FVC (L)	FVC % Pred	FEV_1 (L)	FEV_1/FVC %
Good Effort	4.90	91	4.16	85
Error	4.40	82	4.16	96



Problem: Airflow during exhalation may suddenly cease before the lungs have been completely emptied.

Identification: Closing the vocal cords (glottis closure) and breath holding both cause the volume-time curve to show an abrupt horizontal line (left). The flow-volume curve drops sharply to zero flow (right).

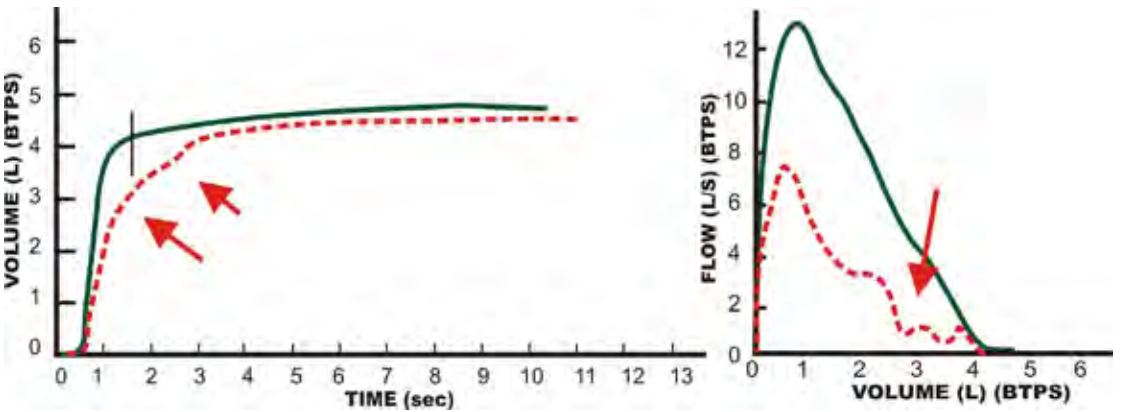
Test Result Implications: The FVC is falsely reduced and may be misinterpreted as indicating a "restrictive impairment." In addition, the FEV_1/FVC ratio may be falsely elevated, resulting in normal FEV_1/FVC even when the subject has a mild obstructive impairment.

Solution: Glottis closure may be involuntary and should be documented. However, for breath holding, coach the subject to blow UNTIL TOLD TO STOP.

Spirometer Error Message: Some spirometers will label this error with "Blow out longer" or "Abrupt stop."

Error #8: Partially Obstructed Mouthpiece

	FEV_1 (L)	FEV_1 % Pred	FEV_1/FVC%	PEF (L/sec)
Good Effort	4.08	101	87	12.4
Error	3.09	77	68	7.2



Problem: Speed of exhaled air is reduced if the mouthpiece is partially blocked by the subject's tongue, teeth, loose dentures, or strong biting that deforms the shape of the mouthpiece.

Identification: Blockage of the mouthpiece can cause flow-volume and volume-time curves to be misshapen in a variety of ways. The flow-volume curve may have a reduced peak flow and portions of the curve are flattened (right). The volume-time curve may show some flattening after the initial rise of the curve (left). The specific shape of each curve depends upon when and to what degree airflow was reduced — the greater the degree of mouthpiece obstruction, the flatter the curve.

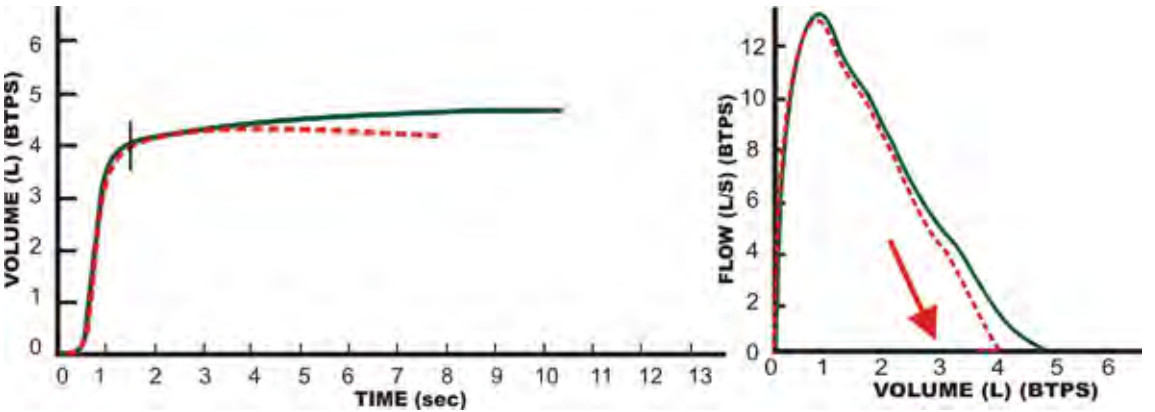
Test Result Implications: The FVC may be reduced if there is sufficient pressure to cause air loss around the mouthpiece. The falsely reduced FEV_1 and FEV_1/FVC ratio may be misinterpreted as indicating an "obstructive impairment."

Solution: Coach the subject to place the mouthpiece between the teeth and on top of the tongue. Securing dentures may be preferable to removing them, as it maintains anatomical integrity and promotes proper lip seal. Lightly biting on (but not deforming) the mouthpiece usually helps unless the dentures are very poorly fitted.

Spirometer Error Message: Many spirometers will not label these curves as erroneous, so health professionals must recognize these patterns.

Error #9: Leak

	FVC (L)	FVC % Pred	FEV_1 (L)	FEV_1/FVC%
Good Effort	4.71	80	4.05	86
Error	4.35	74	4.05	93



Problem: Leaks in volume-type spirometers equipped with auto-negator springs will cause volume and flow measurements to be falsely low. The leaks can occur in the spirometer, hose, or around the subject's mouthpiece during a maneuver.

Identification: When leaks are large enough to be visualized, they cause the volume-time curve to descend after a plateau is reached (left). They also cause the flow-volume curve to "back-track" toward zero volume at the end of the maneuver (right).

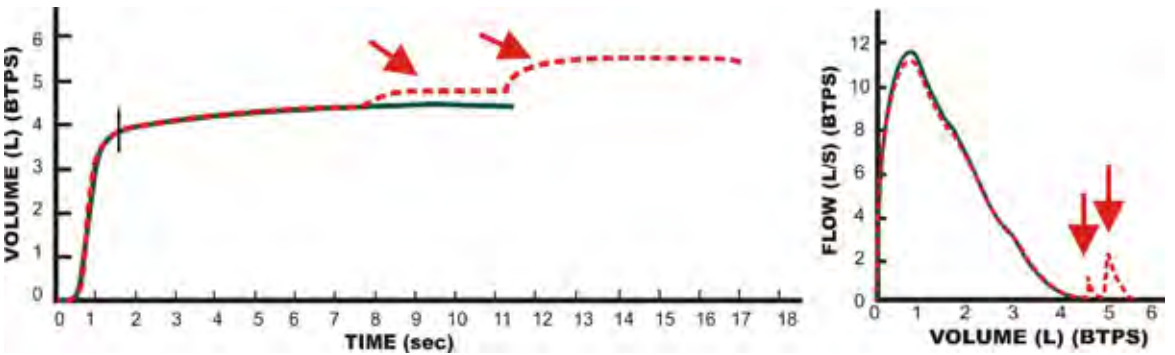
Test Result Implications: When leaks are visible in either graph, the effect on the FVC is likely to be profound. Since the FEV_1 is not much affected, the FEV_1/FVC ratio is often falsely elevated. These false results may prevent the detection of "obstructive impairment" or be misinterpreted as indicating a "restrictive impairment."

Solution: Leaks are more common in volume spirometers. The technician must follow the leak check protocol to determine if it is in the spirometer, the hose, or at the mouthpeice. A flow spirometer system can leak, but will not cause graphs like those displayed. A leak will cause the flow spirometer to fail its calibration check when the syringe is injected slowly. A technician using a flow spirometer needs to check for loose connections or for holes or wear in tubing. Technicians should also ensure that a tight lip seal is maintained by the subject since some dental devices may interfere with a proper lip seal. An astute technician can usually hear air escaping around the mouthpiece.

Spirometer Error Message: Spirometers do not label this error; it must be detected during a calibration check.

Error #10: Extra Breath(s)

	FVC (L)	FVC % Pred	FEV_1/FVC%
Good Effort	4.43	97	88
Error	5.55	122	69



Problem: Subjects sometimes take extra breaths through their nose or around the sides of the mouthpiece at or near the end of the maneuver.

Identification: Extra breaths are easily seen in both displays: the volume-time curve has "steps" added onto the plateau at the end of the exhalation (left) and the flow-volume curve has small curves added after the large curve (right). There may be one or more extra breaths with the artifact size dependent on the amount of air breathed in.

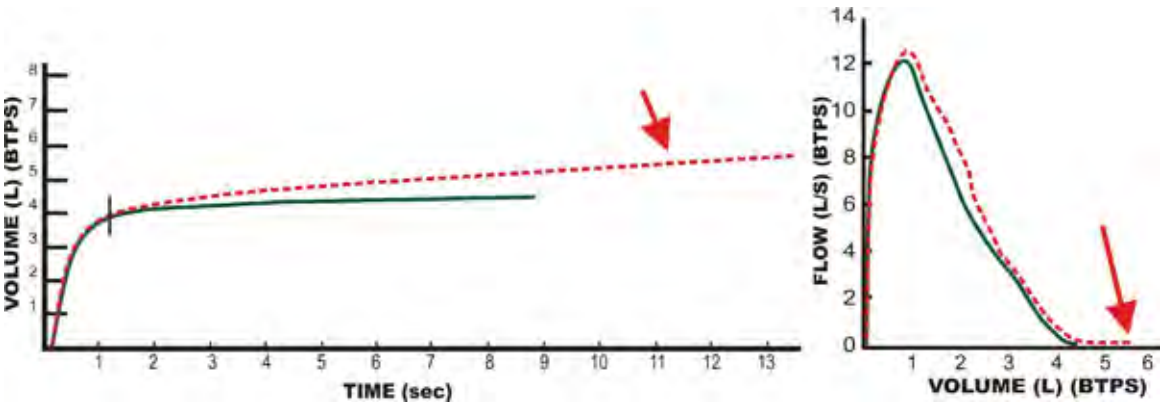
Test Result Implications: The FVC is falsely elevated, though the FEV_1 is not affected, causing a falsely reduced FEV_1/FVC ratio, which may be misinterpreted as indicating an "obstructive impairment."

Solution: Use nose clips and instruct the subject to keep a tight lip seal around the mouthpiece. Since these extra breaths falsely elevate the FVC, the curves must be deleted and not saved with the test results.

Spirometer Error Message: Spirometers do not label this error, so health professionals must recognize these patterns.

Error #11: Positive Zero-Flow Error

	FVC (L)	FVC % Pred	FEV_1 (L)	FEV_1 % Pred	FEV_1/FVC%
Good Effort	4.41	85	3.87	95	88
Error	5.68	109	3.93	96	69



Problem: A positive zero-flow error (in a flow-type spirometer) causes over-recording of all expiratory measurements. This error can occur when the zero flow reference point is set incorrectly.

Identification: Positive zero-flow errors may cause the volume-time curve to rise at a constant rate and never plateau (left). The angle of the rise depends on the severity of the zero error — the greater the error, the steeper the slope. The flow-volume curve shows a long tail at the end of expiration that remains at constant positive flow (right).

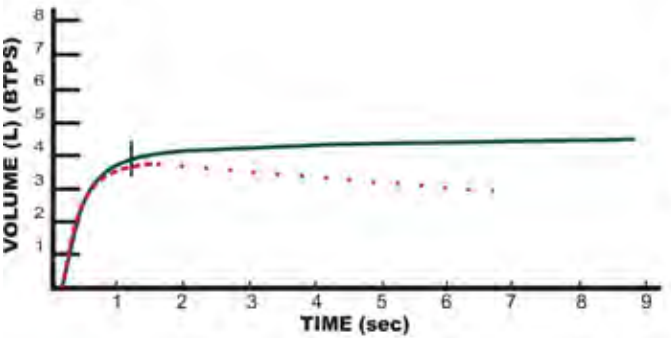
Test Result Implications: The FVC is more affected than the FEV_1 causing a falsely reduced FEV_1/FVC ratio which may be misinterpreted as indicating an "obstructive impairment."

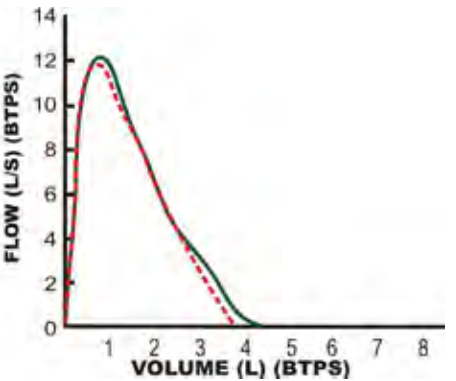
Solution: Many flow-type spirometers are susceptible to zero-flow errors. To prevent these errors, the technician should block the sensor outlet to prevent air motion through the sensor while the zero flow reference is set. Sensors should be held upright and still during subject testing. Some spirometers determine zero flow before each maneuver, whereas other spirometers measure it only once before a subject's set of maneuvers. Zero errors are likely to vary in the former case, but curves will be consistently incorrect in the latter case. All curves recorded with zero errors must be deleted.

Spirometer Error Message: Spirometers do not label these errors, so health professionals must recognize these patterns.

Error #12: Negative Zero-Flow Error

	FVC (L)	FVC % Pred	FEV_1 (L)	FEV_1 % Pred	FEV_1 /FVC%
Good Effort	4.41	85	3.87	95	88
Error	3.81	73	3.63	89	95





Problem: A negative zero-flow error (in a flow-type spirometer) can cause under-recording of all expiratory measurements. The degree to which under-recording occurs depends on the severity of the zero flow error. This error can occur when the zero flow reference point is set incorrectly.

Identification: A negative zero-flow error may cause the volume-time curve to end abruptly or it might drop gradually toward zero volume (left), similar to a large leak.

Test Result Implications: The FVC is more affected than the FEV_1, causing a falsely increased FEV_1/FVC ratio. These results may be misinterpreted as indicating a "restrictive impairment" or might obscure a true "obstructive impairment."

Solution: Many flow-type spirometers are susceptible to zero-flow errors. To prevent these errors, the technician should block the sensor outlet to prevent air motion through the sensor while the zero flow reference is set. Sensors should be held upright and still during subject testing. Some spirometers determine zero flow before each maneuver, whereas other spirometers measure it only once before a subject's set of maneuvers. Zero errors are likely to vary in the former case, but curves will be consistently incorrect in the latter case. All curves recorded with zero errors must be deleted.

Spirometer Error Message: Spirometers do not label these errors, so health professionals must recognize these patterns.

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