Supplemental Material for:

Standardization of Spirometry – 2019 Update: An Official American Thoracic Society and European Respiratory Society Technical Statement (1)

Authors:
Brian L. Graham, Irene Steenbruggen, Martin R. Miller, Igor Z. Barjaktarevic, Brendan G. Cooper, Graham L. Hall, Teal S. Hallstrand, David A. Kaminsky, Kevin McCarthy, Meredith C. McCormack, Cristine E. Oropez, Margaret Rosenfeld, Sanja Stanojevic, Maureen P. Swanney, Bruce R. Thompson, on behalf of the American Thoracic Society and European Respiratory Society

Online Supplemental material:

| Section | Page |
|---------|------|
| E1      | 2    |
| E2      | 4    |
| E3      | 21   |
| E4      | 22   |
| E5      | 24   |
| E6      | 27   |
| E7      | 29   |
| E8      | 30   |
| E9      | 32   |
| E10     | 35   |
| E11     | 39   |
| E12     | 41   |
| E13     | 42   |

Correspondence:
Brian L Graham, Division of Respirology, Critical Care and Sleep Medicine, University of Saskatchewan, Saskatoon, SK, Canada S7N 0W8, email: brian.graham@usask.ca
Section E1. 2019 Update changes from the ATS/ERS 2005 Spirometry Standards (2).

Table E1. Summary of primary changes.

1. **Relative Contraindications:**
   A new list of relative contraindications to be considered when ordering spirometry was added. The former contraindication of testing within one month of myocardial infarction is changed to one week. [Recommendations are based on publications (3-13) and task force experience and assessment of current best practices.]

2. **Equipment:**
   Spirometers are now required to meet ISO 26782 standards, with the exception that spirometry equipment must have a maximum permissible error of ±2.5% for accuracy, linearity and repeatability when tested with a 3 L calibration syringe and when using the test profiles of ISO 26782 Section 7 Annex C, which replaces the 2005 Standards use of the ATS standardized waveforms. [Recommendations are based on publications (14-17), a survey of current best practices of spirometer manufactures and task force experience.]

3. **Device Quality Assurance:**
   Procedures were updated to meet the new accuracy requirement. Procedures regarding calibration verification were updated. [Recommendations are based on publications (15-20), a survey of current best practices of spirometer manufactures and task force experience.]

4. **Operator Details:**
   Operator training and attainment and maintenance of competency must be integrated into any spirometry testing service. [Recommendations are based on publications (21-27) and task force experience and assessment of current best practices.]

5. **Patient Details:**
   The list of activities that patients should avoid prior to testing was updated. [Recommendations are based on task force experience and assessment of current best practices.]

6. **FEV1 and FVC Maneuver:**
   The new standards focus on the use of devices that measure both expiration and inspiration, with four distinct phases to the FVC maneuver: 1) maximal inspiration; 2) a “blast” of expiration; 3) continued complete expiration for a maximum of 15 s; and 4) inspiration at maximal flow back to maximum lung volume. [Recommendations are based on task force experience and assessment of current best practices.]

7. **Maneuver acceptability and repeatability:**
   The maximum acceptable back-extrapolated volume was reduced to <5% of the FVC or 0.100 L, whichever is greater. The rise time from 10% to 90% of peak flow should be ≤150 ms.

   Previous standards used the term “end of test” and the abbreviation “EOT” to denote the end of forced expiration. These standards stress the importance of a maximal inspiration following the forced expiration. As such, the End Of Forced Expiration is not the end of the maneuver, and hence, the term EOFE is used. There are new criteria for an acceptable EOFE.
and the previous requirement of a minimum expiratory time was eliminated. If the volume of the maximal inspiration (FIVC) following EOFE is greater than FVC, then maneuvers with FIVC - FVC > 0.100 L or 5% of FVC, whichever is greater, are not acceptable. For children age ≤ 6 yr, the difference between two largest FEV₁ values and the two largest FVC values must be ≤ 0.100 L or 10% of the highest value, whichever is greater. A table of standard warning messages is provided to alert the operator of potential problems in each maneuver. Criteria are provided for determining whether FEV₁ and FVC measurements that are not acceptable may still be clinically useful. [Recommendations are based on publications (28-45) and task force experience and assessment of current best practices.]

8. **Bronchodilator responsiveness testing:**
The previous term “reversibility testing” is replaced by “bronchodilator responsiveness testing” to avoid the unwarranted inference that “reversibility” implies the complete elimination of airway obstruction. A new table of bronchodilator withholding times is provided. An example procedure for bronchodilator administration by nebulizer is provided in addition to an updated bronchodilator administration by metered dose inhaler. The system is required to issue a warning message if the time between the last pre-bronchodilator maneuver and the first post-bronchodilator maneuver is less than the required wait time for response to the bronchodilator. [Recommendations are based on publications (46-59) and task force experience and assessment of current best practices.]

9. **Grading the quality of the test session:**
A grading system based on the 2017 ATS Recommendations for a Standardized Pulmonary Function Report should be used. [Recommendations are based on publications (42, 60-61) and task force experience and assessment of current best practices.]

10. **Operator feedback:**
A drop-down menu for standardized operator feedback is required which promotes synoptic reporting and provides a quick quality control checklist for the operator. [Recommendations are based on task force experience and assessment of current best practices.]

11. **VC and IC maneuvers:**
The repeatability criterion is changed. The difference in VC between the largest and next largest maneuver must be ≤ 0.150 L or 10% VC, whichever is smaller, for age > 6 yr and ≤ 0.100 L or 10% VC, whichever is smaller, for age ≤ 6 yr. [Recommendations are based on task force experience and assessment of current best practices.]

12. **Other:**
Maximal voluntary ventilation maneuvers, separate peak flow maneuvers and unattended (home monitoring) spirometry are not included in these standards.
Section E2. Flow-volume and volume-time graphs.

Additional specifications for flow-volume and volume-time graphs

1. The scales of the graphs should be adjusted to maximize the data plots within the available space on the report form and the real-time display. Operators and interpreters need to be able to see the details of the graphs which are lost when graphs from a person with small lungs are displayed on a fixed scale designed for larger lung volumes. For the real-time display, an initial scale that accommodates 120% of the predicted FVC could be used for a new patient and then adjusted as needed as patient data are acquired. The aspect ratio of 2 L/s to 1 L for the flow-volume graph must be maintained when the graph is rescaled.

2. For volume-time graphs, the time axis must begin at one second before time zero unless the time point of maximum inspiratory volume occurs earlier, in which case the time axis starts at the nearest second before the time point of maximum inspiratory volume.

3. For flow-volume graphs, the volume axis should begin at -1 L for maneuvers with FVC ≥ 3 L, which may be reduced to -0.5 L for maneuvers with FVC < 3 L. In maneuvers with FIVC > FVC, the volume axis must begin with a negative volume offset larger than the difference between FIVC and FVC.

4. Graphs should have horizontal and vertical grid lines. Vertical axis labels should be applied at the left most grid line. For flow-volume graphs, axis labels should be applied at the lowest grid line.

5. Use bold vertical grid lines at zero volume on flow-volume graphs and at time zero on volume-time graphs.

6. Use bold horizontal grid lines (or axis lines) at zero flow on flow-volume graphs and at zero volume on volume time graphs.

7. When more than one maneuver is plotted superimposed on the same graph, e.g. pre- and post-bronchodilator maneuvers, different colors should be used for each maneuver.
Figure E1. An acceptable maximal maneuver by a normal male (age 68.4 yr). The flow-volume graph has a fast start and sharp peak with a smooth drop to zero flow. There is a steep slope at the start of the volume-time curve with a plateau at the end of expiration. (reproduced with permission – RESPTREC™ Spirometry Training Course, Lung Association of Saskatchewan, www.resptrec.org)
Figure E2. An acceptable maximal maneuver by a normal male (age 4.0 yr). Note the convex shape of the forced expiratory flow segment of the flow-volume curve which is often seen in healthy children with high elastic recoil. Such children can empty their lungs quickly and may not be able to hold an expiratory plateau for 1 s. Note that complete expiration was attained in less than 2 s, even though the plateau was not held for 1 s. In this patient, the FVC was provisionally acceptable following this maneuver and was judged to be acceptable when it was found to be within 0.100 L of the FVC from subsequent maneuvers.
Figure E3. An acceptable maximal maneuver by a female (age 52.6) yr with very severe obstruction. Note that no plateau was reached by 15 s of expiration. (reproduced with permission – RESPTREC™ Spirometry Training Course, Lung Association of Saskatchewan, www.resptrec.org)
Figure E4. An acceptable maximal maneuver by a male (age 77.3 yr) with restrictive lung disease. Note that a plateau was reached in less than 3 s of expiration. (reproduced with permission – RESPTREC™ Spirometry Training Course, Lung Association of Saskatchewan, www.resptrec.org)
Figure E5. An acceptable maximal maneuver by a male (age 11.0 yr) with uncontrolled asthma. Note the concave shape of the expiratory flow-volume curve. (reproduced with permission – RESPTREC™ Spirometry Training Course, Lung Association of Saskatchewan, www.resptrec.org)
Figure E6. A sub-maximal effort is characterised by a rounded flow-volume curve and a less steep slope at the start of the volume-time curve. Compare a sub-maximal effort (solid line) to an acceptable maneuver (dashed line) in the same subject. A sub-maximal effort will often have a rise time >150 ms which will trigger a warning – see Section E8. (reproduced with permission – RESPTREC™ Spirometry Training Course, Lung Association of Saskatchewan, www.resptrec.org)
Figure E7a. A cough is seen as blips in the flow-volume graph. The volume-time graph shows that the initial cough occurred in the first second of expiration. The dashed orange line on the flow-volume graph is at the point of FEV₁ on the volume axis and more clearly shows that the initial cough occurred in the first second. (reproduced with permission – RESPTREC™ Spirometry Training Course, Lung Association of Saskatchewan, www.resptrec.org)
Figure E7b. A cough later in expiration. In this example, the volume-time graph does not clearly indicate the start of the cough. The dashed orange line at FEV₁ on the flow-volume graph shows that the cough occurred later than 1 s and thus the FEV₁ and FVC measurements are acceptable.
Figure E8. A false start occurs when the subject reaches total lung capacity and leaks out some air before beginning a forced expiration. In this example the back extrapolated volume is 0.475 L which exceeds 5% of FVC and therefore the FVC and FEV₁ are unacceptable. (reproduced with permission – RESPTREC™ Spirometry Training Course, Lung Association of Saskatchewan, www.resptrec.org)
Figure E9. Glottis closure: note the sudden drop in flow in the flow-volume graph and the flat line after 1.25 seconds in the volume-time graph. Compare the glottis closure (solid line - FVC = 4.4 L) to an acceptable maneuver (dashed line - FVC = 5.2 L) in the same subject. In both cases, FEV₁ = 4.3 L.
(reproduced with permission – RESPTREC™ Spirometry Training Course, Lung Association of Saskatchewan, www.resptrec.org)
Figure E10. When the inspiratory volume at the end of the maneuver exceeds the forced expiratory volume, the subject did not reach total lung capacity before blowing out. The maneuver is not acceptable if the inspiratory volume exceeds the FVC by more than 0.100 L or 5% of FVC, whichever is greater. In this example, neither FEV₁ nor FVC is acceptable. *(reproduced with permission – RESPTREC™ Spirometry Training Course, Lung Association of Saskatchewan, www.resptrec.org)*
**Figure E11.** When a subject has a slow start to expiration, the flow-volume curve may still show a peak but it occurs later in expiration. In this example, the rise time from 10% to 90% of peak flow is 320 ms, well in excess the 150 ms recommendation. *(reproduced with permission — RESPTREC™ Spirometry Training Course, Lung Association of Saskatchewan, www.resptrec.org)*
Figure E12. When the tongue obstructs the mouthpiece, there is a reduced flow and often a flutter can be seen in the flow-volume curve. The flow oscillations (sometimes referred to as sawtoothing) seen in this flow-volume curve may also be seen in cases of upper or central airway obstruction. (reproduced with permission – RESPTREC™ Spirometry Training Course, Lung Association of Saskatchewan, www.resptrec.org)
Figure E13. Hesitation time is defined as the time from attaining maximum inspired lung volume to the back-extrapolated time zero which should be less than 2 s. The upper panel shows an acceptable maneuver with a hesitation time of 0.62 s. The lower panel shows a maneuver from the same person but with a hesitation time of 2.21 s which should generate a warning and a message to instruct the patient to blast out immediately when completely full.
Figure E14a. The effect of a zero-flow offset caused by flow through the sensor while the system is in an auto-zero routine. These examples show simulated zero-flow offsets of +0.025 L/s (upper panel) and -0.025 L/s (lower panel). The blue lines are the simulated offsets and the dotted orange lines are the actual data with no zero-flow offset.

A positive zero-flow offset (upper panel) causes the expiratory volume to be overestimated and is seen as a steady increase in volume rather than reaching a plateau in the volume-time graph. It causes the tidal volume loops in the flow-volume graph prior to forced exhalation to progressively move to the right. A positive zero-flow offset also causes an underestimation of the inspiratory volume.

A negative zero-flow offset (lower panel) causes the expiratory volume to be underestimated and may not be obvious in the volume-time graph. The tidal volume loops in the flow-volume graph move progressively to the left. The inspiratory VC is overestimated and may be confused with a maneuver where the patient did not attain TLC before the forced expiration.

FEV₁ and FVC from maneuvers with an erroneous zero-flow offset are not acceptable.

Spirometry systems should not pass the auto-zero procedure if variable flow is detected during the procedure or if there is a significant change in the zero-flow level.
Figure E14b. A second example of the effect of a larger zero-flow offset caused by flow through the sensor while the system is in an auto-zero routine. These examples show simulated zero-flow offsets of +0.050 L/s (upper panel) and -0.050 L/s (lower panel). The blue lines are the simulated offsets and the dotted orange lines are the actual data with no zero-flow offset. The effects noted in figure 14a are more obvious in this example.
Section E3: Terms used in the literature search.

A search for terms related to spirometry using PubMed was conducted in February 2018. The number of citations from 2004 to February 2018 was as follows. Search terms were applied to the title and/or abstract. Note that citations already identified in set 1 were excluded from set 2. Similarly, citations already identified in sets 1 and 2 were excluded from set 3.

| set | terms | number of citations |
|-----|-------|---------------------|
| 1   | spirometer(s) OR spirometry OR spirometric(s) | 9796 |
| 2   | pulmonary function test(s) OR lung function test(s) | 5207 |
| 3   | FEV1 OR FVC | 8365 |
| Total | | 23,368 |

The citations from set 1 were divided among the task force members to review for relevancy and coded as directly relevant, potentially relevant, relevant for reference values or not relevant. In most cases, relevancy could be determined from the title and abstract. The citations from sets 2 and 3 were judged by two reviewers (BLG and MRM). The result was that 190 were deemed to be directly relevant, 382 potentially relevant and 203 related to reference values.

The task force continued to monitor new publications during the course of the development of the standards. Several related new publications were identified and reviewed, of which 11 publications from 2018 and 2019 were cited in the updated standards.
Section E4: Key messages from a survey of spirometry patients

A preliminary analysis of an online survey completed by 1760 spirometry patients from 52 countries conducted in August and September 2018 by the European Lung Foundation yielded the following key messages. A complete analysis of the results is forthcoming in a future publication. The task force gratefully acknowledges the support of the European Lung Foundation, the work done on this survey by Barbara Johnson, Courtney Coleman and Pippa Powell, and the input from so many patients regarding their spirometry experiences.

Most patients found the level of difficulty of the test to be either mostly acceptable or completely acceptable

Though many patients gave suggestions about how spirometry testing could be improved, it is important to note that 90% of patients found spirometry testing acceptable and not problematic. While some patients found the test to be uncomfortable, they felt it was a necessary, temporary discomfort.

Some small changes can make the process more pleasant

Patients would like to have water, tissues and sputum pots provided without having to ask. Patients would like a recovery period between maneuvers and not to feel rushed. Patients would like somewhere to sit to recover for a few minutes afterwards. Patients would like privacy when completing spirometry – some patients were embarrassed by their difficulty in completing the test, others had concerns about infection due to their lung condition.

Give clear information about what to expect during the test

Patients felt that it is very important to be prepared for what is going to happen during the test and then to be coached through the process.

Patients want access to spirometry results and their meaning

Patients want to be able to understand their results and what they mean for them. Many reported not understanding what their results mean. They would like to be able to have access to these results (either paper results or available digitally) and be able to compare them to their previous results. Some respondents requested a comparison to normal values for healthy persons with the same age, height, and weight or for someone with their condition. Patients would like these results and explanations without having to ask for them. Patients would also like to know whether there is anything they could do to improve their results. They feel this would be important information at the end of a spirometry test.

The operator is of great importance

Many patients emphasized the importance of the operator. Those who have had several tests felt that it made a real difference how friendly and encouraging the operator was. Some felt that the operator needed to fulfil the role of a cheerleader and that it made a difference to their results. Patients also felt that operators need to “have empathy before, during and after
the maneuver” and that it is important to check if the patient is ready and how they feel about performing the next maneuver.

Patients also felt that it was important that operators did not express disappointment when patients have trouble completing the test. Though many felt that encouragement or coaching is important, some patients would have preferred a gentler approach rather than shouting instructions to blow.

**Spirometry testing is very worrying for some**

Some patients were very concerned about the test and some expressed feeling anxiety about the results. Some felt vulnerable and found the process embarrassing especially when they found the test hard to do or expectorated sputum.

**Give clear instructions about medication use prior to spirometry testing**

One quarter of patients felt that they were not given clear guidance about using their prescribed medications before the test. Some patients would like a reminder a week before the test regarding which medications they should withhold and for how long.

**Design the testing station with the patient in mind**

Some patients suggested that having equipment that could be adjusted to suit their size and posture would be helpful as sitting awkwardly is not conducive to achieving good results.
Section E5: Calculation of the ATPH to BTPS factor

A conversion factor is required to adjust the flow and volume measured by the spirometer to body conditions. Air that is inspired from the room will expand in the lungs since it is heated to body temperature and saturated with water vapor. Body conditions are denoted BTPS: **Body Temperature** (310°K); ambient barometric **Pressure** ($P_b$); **Saturated with water vapor**.

Room air conditions are denoted ATPH*: **Ambient Temperature** ($T_{amb}$); ambient barometric **Pressure**; ambient **Humidity**. At body temperature, the partial pressure of saturated water vapor ($P_{H_2O sat}$) is 47.1 mmHg or 6.28 kPa. $P_{H_2O sat}$ depends on air temperature and is independent of the barometric pressure. To determine the ambient partial pressure of water vapor ($P_{H_2O amb}$) in room air, it is necessary to multiply the saturated pressure by the relative humidity (RH):

$$P_{H_2O amb} = P_{H_2O sat} \times RH$$

The ATPH to BTPS conversion factor for lung volume ($V$) is calculated as follows:

$$\frac{V_{BTPS}}{V_{ATPH}} = \frac{T_{body}}{T_{amb}} \times \frac{P_b - P_{H_2O amb}}{P_b - P_{H_2O body}}$$

Note that the temperature is in degrees Kelvin which is found by adding 273 to the temperature in degrees Celsius.

If absolute barometric pressure is not available, altitude can be used to estimate $P_b$, using the following formula† where $h$ is the altitude above sea level in m:

$$P_b (\text{mmHg}) = 760 \left(1 - 2.25577 \cdot 10^{-5} \cdot h\right)^{5.25588} \text{ or } P_b (\text{kPa}) = 101.325 \left(1 - 2.25577 \cdot 10^{-5} \cdot h\right)^{5.25588}$$

When using $P_b$ from a local weather station, be aware that they usually report the barometric pressure adjusted to sea level. Confirm that the value is the absolute $P_b$ before using it.

* The term ATPS is used for volume based spirometers in which the exhaled gas is assumed to have cooled to ambient temperature but remained saturated with water vapor. Hence ATPS implies **Ambient Temperature and Pressure**, Saturated with water vapor. ATPD, where D stands for **Dry**, is used for dry gas such as gas from compressed cylinders. For ambient room air conditions, some authors have simply used ATP which gives no specification regarding humidity. In this section, the term ATPH is used to clearly indicate that the inspired gas is at **Ambient Temperature**, ambient **Pressure** and ambient **Humidity** and that it is therefore necessary to consider the ambient humidity when converting the measured inspiratory volume to BTPS.

†The Engineering ToolBox. Altitude above Sea Level and Air Pressure. https://www.engineeringtoolbox.com/air-altitude-pressure-d_462.html
This graph shows the error that results in the BTPS factor when the actual ambient room temperature is different from the value entered into the spirometry system. Ambient barometric pressure is 760 mmHg (101.3 kPa) and ambient relative humidity is 40%. Note that errors in the BTPS factor translate directly to errors in the measured volumes and flows.

This graph shows the error that results in the BTPS factor when the actual ambient relative humidity in the room is different from the value entered into the spirometry system. Ambient barometric pressure is 760 mmHg (101.3 kPa) and ambient temperature is 22°C. Note that errors in the BTPS factor translate directly to errors in the measured volumes and flows.
These graphs show the error that results in the BTPS factor when the actual barometric pressure is different from the value entered into the spirometry system. Ambient room temperature is 22°C and ambient relative humidity is 40%. Note that errors in the BTPS factor translate directly to errors in the measured volumes and flows. Changes in barometric pressure have a relatively small effect (62).
Section E6: Estimating height using ulna length or arm span

The patient’s height is an important factor in determining the predicted values for spirometric variables. Its measurement is hindered if the patient is unable to stand fully erect. Ulna length is an accessible and accurate surrogate that can be used for adults and children. In the sitting position, the left forearm rests on a flat surface with the palm faced downwards, and fingers extended and together. The elbow is bent at 90° to 110°, where the proximal end (olecranon process) of the ulna can be palpated, and then moving distally to the styloid process. The tips of the calipers are placed at both end points. An illustration of the measurement technique is given in figure 1 of the Gauld study (63). The following table provides equations to estimate height from ulna length.

**Prediction equations for height in cm using ulna length in cm (UL) and age (A) in males (M) and females (F) for various ages and ethnicities**

| Prediction Equation | Study sample |
|---------------------|--------------|
| M: 4.605·UL + 1.308·A + 28.003 | Gauld 2004 (63) - predominantly Caucasians 2343 (M=1144, F=1199), age 5-19 yr |
| F: 4.459·UL+ 1.31·A + 31.485 | |
| M <65 yr: 3.2·UL + 84.5 | Barbosa 2012 (64) 507 (432 English, 75 Portuguese) M=229; F=203 |
| M ≥65 yr: 3.2·UL + 84.7 | Mean age 61.8±18.9 |
| F <65 yr: 2.9·UL+ 92.0 | Weidauer2014 (65) - 325 American (SD and UT) children, age 0-5.9 yr |
| F ≥65 yr: 3.3·UL+ 78.5 | |
| M<6 yr: 3.64·UL + 9.76·A - 2.9·A·ln(A) + 23.86 | Chen 2018 (66) - 512 Taiwanese, age 1-17 yr |
| F<6 yr: 3.04·UL + 11.98·A - 3.53·A·ln(A) + 27.45 | |
| M & F < 18 yr: 3.596·UL + 2.289·A + 36.406 | Chen 2018 (66) - 512 Taiwanese, age 1-17 yr |
| M: 3.16·UL + 85.61 | Bonell 2017 (67) 620 Vietnamese adults, age 21-65 yr |
| F: 2.97·UL + 85.80 | |
| M <65 yr: 3.60·UL + 79.2 | MUST 2003 (68) (Malnutrition Universal Screening Tool) |
| F <65 yr: 2.77·UL + 95.6 | |

Current literature uses linear regression analysis to develop prediction equation for height using ulna length. A study found no significant difference between actual height and estimated height from UL; however, the limits of agreement between measures were large (95% confidence range = 7.5 cm) (63). The ethnic diversity of current studies is limited, and therefore studies in other ethnic populations would be valuable.

Height may also be estimated using arm span. Arm span is measured from the tip of the middle finger on one hand to the tip of the middle finger on the other hand with the patient standing against the wall with both arms abducted to 90°, the elbows and wrists extended, and the palms facing directly forward. Because the patient's arm span will often be close to or greater than the operator's arm span, the measurement is done in two steps. Measure from the tip of the left middle finger to a point at the center of the spine (which is marked with a pen). Then
measure from the same point to the tip of the right middle finger and add the two measurements. The preferred method to calculate height from arm span is using the Quanjer equations (69) which provide adjustments for sex, age and ethnic origin. A calculator for arm span to height calculations is available for download from: https://spirxpert.ers-education.org/en/download/armspan-to-height-software/

Spirometry systems should include the ability to estimate height from ulna length or arm span.
Section E7: Ethnicity categories for the Global Lung Function Initiative (GLI) reference values (70).

Operators have frequently requested guidance in regard to which ethnicity category should be used to obtain the GLI spirometry reference values. The ethnicity categories were developed using data from four broad regions as follows.

| Group               | Country/region                                                   |
|---------------------|------------------------------------------------------------------|
| Caucasian (i.e. European Ancestry) | Europe, Israel, Australia, USA, Canada, Mexican Americans, Brazil, Chile, Mexico, Uruguay, Venezuela, Algeria, Tunisia |
| Black               | African American                                                 |
| South East Asian    | Thailand, Taiwan and China (including Hong Kong) south of the Huaihe River and Qinling Mountains |
| North East Asian    | Korea and China north of the Huaihe River and Qinling Mountains  |
| Other               | Persons not from the above regions. An average of the predicted values using the above four groups will be generated. |

In addition to the countries that contributed data for the GLI reference values (listed in the above table), it would be reasonable to apply the group reference equations to others with geographic or ethnic proximity. Thus the Caucasian equations could be used for any person having origins in any of the original peoples of Europe, the Middle East, or North Africa and for any non-indigenous person of South America. Until further data are available, African-American equations can be used for individuals of African descent. Similarly, the Southeast Asian equations may be reasonably extended throughout that region.

However, significant populations remain missing, including Native Americans, Alaska Natives, the Indian sub-continent residents, Africans and Japanese. There are many reports of spirometry reference values (and some for other tests) from individual countries or ethnic groups, but the population size and data quality may vary. Within the Indian sub-continent, there appear to be regional differences in spirometry values that cannot be encompassed in the same equations (71).

GLI-2012 provides a fifth set of equations, “Other”, using a combination of the other four groups, which may be applied as a first approximation to individuals not represented by one of the groups or who are of mixed ethnicity. This should be noted in the report and the results should be interpreted with awareness of increased uncertainty.

If birth sex and/or ethnicity data are not disclosed, the operator notes must alert the interpreter of this omission and state what default values were used for calculating predicted values. Tools for calculating GLI predicted values are accessible at www.lungfunction.org
**Section E8: System warning messages generated by analysis of the flow and volume signals**

These warning messages are designed to assist the operator in her/his evaluation of each maneuver. Spirometry software can provide objective measures related to the maneuver acceptability criteria (Table 7 of the spirometry standards document, or Table 5 of the executive summary) and other indicators of maneuver performance, but does not supplant the role of the operator to assess test quality.

| Warning trigger                          | Warning message                  | Instruction to patient                                           |
|------------------------------------------|----------------------------------|-----------------------------------------------------------------|
| BEV exceeds limit                        | hesitant start                   | blast out immediately when completely full                      |
| rise time > 150 ms*                      | slow start                       | blast out immediately when completely full                      |
| no plateau and expiration < 15 s         | no plateau                       | keep going until completely empty                               |
| hesitation time > 2 s                    | hesitation at maximum volume     | blast out when completely full                                  |
| FVC less than max FVC from previous maneuvers | low forced expiratory volume | take the deepest breath possible and keep going until completely empty |
| FIVC > FVC                               | incomplete inspiration prior to FVC | fill your lungs completely before blasting out – take the deepest breath possible |
| FIVC < 90%FVC                            | low final inspiration            | after completely emptying your lungs, remember to breathe in - back to the top |
| mean inspiratory flow of the breath just prior to forced expiration is less than 2 L/s | slow filling         | breathe in faster before blasting out                            |
| suspected glottis closure†              | abrupt stop                     | if you feel your throat closing, relax, but keep pushing         |
| suspected cough in first second of expiration‡ | cough in first second of expiration | try having a sip of water before the next blow                   |

*A rise time > 150 ms is often associated with a sub-maximal expiratory effort, characterized by a rounded flow-volume curve (figure E6), resulting in an erroneous FEV$_1$. Additionally, the FVC may be overestimated since there may be less gas trapping with an unforced expiration compared to a true maximal expiratory effort. The system will prompt the operator to confirm whether this was a submaximal effort, and if so, the FEV$_1$ and FVC will be flagged as unacceptable.

†Suspect glottis closure when there is a sharp drop in expiratory flow (e.g. flow drops from more than 0.100 L/s to less than 0.010 L/s in less than 60 ms within the last 0.050 L of forced expiration).
expiration and the flow-volume curve is concave). For suspected glottis closure, the system will prompt the operator to confirm whether glottis closure occurred. If glottis closure in less than 1 s of expiration is confirmed by the operator, FEV₁ and FVC will be flagged as being not acceptable and not useable. If glottis closure after 1 s of expiration is confirmed by the operator, FVC will be flagged as being not acceptable. Having the patient maintain slight elevation of the chin during the entire forced exhalation may help some patients that exhibit glottis closure when they tilt the head downward during the forced exhalation.

‡Suspect a cough if the forced expiratory segment of the flow-volume graph has spikes (e.g. an up-and-down flow spike ≥0.5 L/s and/or a down-and-up flow spike that drops to < 0.010 L/s). If cough is detected, a dashed vertical line should be drawn at volume = FEV₁ on the flow-volume graph (figure E7). For suspected cough, the system will prompt the operator to confirm whether cough occurred in the first second of expiration. If cough in less than 1 s of expiration is confirmed, FEV₁ will be flagged as being not acceptable and not useable. For children ≤ 6 yr, if cough in less than 0.75 s of expiration is confirmed, FEV₀.₇₅ will be flagged as being not acceptable and not useable. Having the patient inhale less quickly prior to forced exhalation may reduce coughing. The operator should have the option of displaying a vertical dashed line at FEV₁ on the flow-volume graph for all maneuvers.

Note: Some spirometry systems currently have more advanced signal processing algorithms to detect cough and/or glottis closure. The examples given here are suggestions to consider in the development of such algorithms and are not meant to replace existing algorithms.

| Warning trigger | Warning message | Action required |
|-----------------|-----------------|-----------------|
| time elapsed from the last pre-bronchodilator maneuver to the first post-bronchodilator maneuver is less than the wait time | bronchodilator wait time not met | confirm that the bronchodilator has been given and wait the appropriate time |
| time elapsed between two pre-bronchodilator maneuvers exceeds the bronchodilator wait time | excess time between pre-bronchodilator maneuvers | confirm whether the current maneuver is actually post-bronchodilator |
| acceptable calibration verification not done on the day of testing | calibration verification not done today | perform calibration verification before testing patients |

Note: Some spirometry systems may have other warnings which may continue to be used in addition to those in the above tables.
Section E9: Bronchodilator responsiveness testing protocol

Every facility conducting bronchodilator responsiveness testing must have a written protocol for conducting the test. An example of the full procedure is included in the ATS Pulmonary Function Laboratory Management and Procedure Manual (72). The protocol must include the following components:

1. The bronchodilator to be used
2. The dose of the bronchodilator
3. The method of administering the bronchodilator
4. The wait time between the administration of the bronchodilator and the first post-bronchodilator spirometry maneuver

A facility may have different protocols to be followed for different groups of patients, e.g. one for children and one for adults. Spirometer manufactures should provide the ability for the default bronchodilator type(s), dose(s) and wait times in the facility protocol to be included in the facility configuration menu so that the operator is not required to enter this information for each patient.

This example from the 2005 ATS/ERS Spirometry Standards (2) has become the default protocol for most spirometry facilities, and will likely continue to be used as such.

| 1. bronchodilator | albuterol (salbutamol), metered dose inhaler (MDI), 100 µg per actuation* |
| 2. bronchodilator dose | 400 µg delivered as 4 MDI actuations of 100 µg |
| 3. method of bronchodilator administration | After a gentle and incomplete expiration, actuate an albuterol (salbutamol) MDI at the beginning of a slow inhalation to TLC from a holding chamber. The breath is then held for 5-10 seconds before the patient exhales. Four separate MDI actuations are delivered at ~30 s intervals. In young children, or anyone with coordination concerns, a single MDI actuation of albuterol can be inhaled over at least 4 tidal breaths via a holding chamber. In those patients unable to use the holding chamber mouthpiece, a face mask may be used. |
| 4. wait time prior to post-bronchodilator maneuvers | 15 minutes following administration of the final MDI actuation |

*Note that in U.S.A., there is a difference in the way that the emitted dose is measured and the specification for albuterol sulfate is 108 µg per MDI actuation which is equivalent to 100 µg of salbutamol sulfate per MDI actuation in most other countries.
Example protocol using a jet nebulizer to administer the bronchodilator

| 1. bronchodilator | albuterol (salbutamol) using a jet nebulizer |
|-------------------|---------------------------------------------|
| 2. bronchodilator dose | 5 mg nebulizer |
| 3. method of bronchodilator administration | The bronchodilator is administered using a jet nebulizer. Air flow to the nebulizer should be in the range of 6 to 10 L/min with an operating pressure of 50 psi (345 kPa). Nebulizer delivery may be by a mouthpiece or a face mask. Nose clips are optional. Instruct the patient to breathe normally with periodic deep breaths while comfortably seated upright until nebulization is complete, which is usually in the order of 10 minutes. Instruct the patient to breathe only through her/his mouth and to keep the nebulizer vertical during its use. Patients unable to or unlikely to follow instructions should be monitored during nebulization for technique and safety. After the onset of sputter, very little additional drug is inhaled and nebulization can be stopped. |
| 4. wait time prior to post-bronchodilator maneuvers | 15 minutes following completion of the administration of the nebulized dose |

**Considerations for developing a protocol**

The most common choices of bronchodilator for responsiveness testing are: the short-acting beta2-agonist albuterol (known as salbutamol in countries other than U.S.A.); the short-acting muscarinic antagonist ipratropium bromide; or a combination of albuterol and ipratropium. If the bronchodilator is delivered by a nebulizer, the dose, driving flow and delivery time should be specified.

The 2005 ATS/ERS Spirometry Standards example used a dose of 400 µg albuterol or 160 µg ipratropium by MDI to ensure that the response was high on the dose–response curve. A combination of ipratropium bromide and albuterol has demonstrated an increased response compared to either of the individual agents alone in identifying responsiveness in COPD patients (46, 47). Results using doses of 80 µg ipratropium have been reported (46, 47). When using ipratropium only, the recommended wait time is 30 minutes.
When using an MDI in young children (< 5 years) the use of a facemask has been suggested during tidal breathing bronchodilator inhalation, with deposition shown to be similar for those children using a mouthpiece (48). Studies indicate that a valved spacer may not be required (49, 50). For children using a spacer, only a few tidal breaths may be required (51). A study found that a minimum wait time of 20 minutes and a dose of 600 µg of salbutamol was required to document the maximal response to bronchodilators in the majority of asthmatic children (52). However, another study found that shorter wait times were adequate in children (53).

The default bronchodilator type(s) and dose(s) should be included in the facility configuration menu so that the operator is not required to enter this information for each patient.

Operators must be trained in the administration of the bronchodilator. Facilities using nebulizers must be aware that different types of nebulizers may require different bronchodilator doses and delivery times. Follow the manufacturer’s recommendations for their use. For jet nebulizers, 5 mg of albuterol sulfate inhalation solution is nominally equivalent to 400 µg by MDI, and 1 mg of ipratropium bromide inhalation solution is nominally equivalent to 80 µg by MDI (54, 55). The driving gas should be air. Routine use of 100% oxygen as the driving gas for a jet nebulizer for bronchodilator responsiveness testing is not recommended.
Section E10: Spirometry testing session data file requirements.

Data in an easily read, nonproprietary format, such as xml, must be available for the testing session and include all maneuvers within the session as follows. Empty fields or missing values should be marked as “null”. Note that section E11 provides details of the standardized operator comments and the order in which they are entered for parts 1 – 4. All volumes are reported in liters BTPS except for those specified as milliliters BTPS. All flows are reported in liters per second BTPS.

Patient information
- Patient name
- Patient identification code
- Birth sex (M/F/not disclosed)
- Gender identity (text)
- Birth date (yyyy-mm-dd)
- Age (###.# yr)
- Self-reported ethnicity (text)
- GLI ethnicity code (1-5/not disclosed)
- Smoking status (current/former/never)
- Date of test (yyyy-mm-dd)
- Time of test (HH:MM)
- Referring practitioner
- Reason for test
- Height (###.# cm)
- Weight (###.# kg)
- Operator comments for part 1 (Relating to Patient condition)

Lab information
- Testing facility name, city
- Operator ID
- Spirometer model
- Calibration verification date (yyyy-mm-dd)
- Calibration verification time (HH:MM)
- Calibration verification mean error (±#.##%)
- Ambient temperature (## °C)
- Ambient relative humidity (## %)
- Ambient barometric pressure (### mmHg or kPa)

Bronchodilator Information
- Bronchodilator(s) used
- Bronchodilator dose(s)
- Method of delivery (MDI or nebulizer)
- Number of pre-bronchodilator maneuvers
Number of post-bronchodilator maneuvers
Time interval (minutes) between last pre-BD maneuver and first post-BD maneuver
Operator comments for part 3 (Relating to Bronchodilator testing)

Data for each FVC maneuver

Test type (pre- or post-bronchodilator)
Time of start of maneuver (HH:MM)
FEV₁ acceptability (acceptable, useable, neither)
FVC acceptability (acceptable, useable, neither)
FVC
FEV₁
FEV₁/FVC (#.###)
FET (s)
PEF
FIVC
FEV₀.₇₅
FEV₀.₇₅/FVC (#.###)
FEV₆
FEV₁/FEV₆ (#.###)
FEF₂₅–₇₅%
BEV (mL)
10-90% rise time (ms)
Hesitation time (#.## s)
Operator comments for part 2 (Relating to quality of each maneuver)
Warnings issued for the maneuver

Time, flow and volume array data (Time adjusted to “time 0” using back extrapolation. Flow in liters BTPS per second and volume in liters BTPS. Data reported as real numbers at 10 ms intervals.)
Number of data points in the array

Values reported for full FVC session

Reference values source (e.g. GLI-2012)
Pre-bronchodilator FVC
Pre-bronchodilator FVC grade
FVC LLN
Pre-bronchodilator FVC z-score
Pre-bronchodilator FVC percent of predicted
Pre-bronchodilator FET (s)
Post-bronchodilator FVC
Post-bronchodilator FVC grade
Post-bronchodilator FVC z-score
Post-bronchodilator FVC percent of predicted
Post-bronchodilator change in FVC (mL)
Post-bronchodilator change in FVC (%)
Post-bronchodilator FET (s)
Pre-bronchodilator FEV1
Pre-bronchodilator FEV1 grade
FEV1 LLN
Pre-bronchodilator FEV1 z-score
Pre-bronchodilator FEV1 percent of predicted
Post-bronchodilator FEV1
Post-bronchodilator FEV1 grade
Post-bronchodilator FEV1 z-score
Post-bronchodilator FEV1 percent of predicted
Post-bronchodilator change in FEV1 (mL)
Post-bronchodilator change in FEV1 (%)
Pre-bronchodilator FEV1/FVC (#.##)
Post-bronchodilator FEV1/FVC (#.##)
FEV1/FVC LLN
Pre-bronchodilator FEV1/FVC z-score
Post-bronchodilator FEV1/FVC z-score
Pre-bronchodilator FEV0.75
Pre-bronchodilator FEV0.75 grade
FEV0.75 LLN
Pre-bronchodilator FEV0.75 z-score
Pre-bronchodilator FEV0.75 percent of predicted
Post-bronchodilator FEV0.75
Post-bronchodilator FEV0.75 grade
Post-bronchodilator FEV0.75 z-score
Post-bronchodilator FEV0.75 percent of predicted
Post-bronchodilator change in FEV0.75 (mL)
Post-bronchodilator change in FEV0.75 (%)
Pre-bronchodilator FEV0.75/FVC (#.##)
Post-bronchodilator FEV0.75/FVC (#.##)
FEV0.75/FVC LLN
Pre-bronchodilator FEV0.75/FVC z-score
Post-bronchodilator FEV0.75/FVC z-score
Pre-bronchodilator PEF
Post-bronchodilator PEF
Pre-bronchodilator FEV1/FEV6 (#.##)
Post-bronchodilator FEV1/FEV6 (#.##)
Pre-bronchodilator FEF25–75%
Post-bronchodilator FEF25–75%
Operator comments for part 4 (Relating to quality of testing session)

Values reported for each VC and IC maneuver

Time of start of maneuver (HH:MM)
EVC
IVC
IC
ERV

Values reported for full VC and IC test session

EVC
IVC
IC
ERV

Time and volume array data for the maneuver with the largest VC (Data reported as real numbers at 10 ms intervals.)

Number of data points in the array
**Section E11: Standardized operator comments**

The use of these comments is strongly encouraged to promote synoptic reporting and to provide a more rapid and thorough means of generating meaningful operator comments to guide interpretation. For routine cases, only one click for each of the 4 parts listed below may be required. The spirometry system should allow the facility manager to edit the list of comments and add items specific to a given facility or application.

1. **Relating to Patient condition**:
   - No comments
   - First attempt at spirometry
   - Reference values are based on ethnicity that may not be suitable for this patient
   - Patient used bronchodilator(s) prior to test [*prompt for drugs, doses and times used*]
   - Patient smoked < 1 hr prior to test
   - Patient had difficulty understanding directions
   - Patient reported consumption of an intoxicant
   - Observed symptoms e.g. cough, wheeze, dyspnea or cyanosis [*prompt for symptoms*]
   - Other [*prompt for description*]

2. **Relating to quality of each maneuver**
   - No comments
   - Cough during the first second of expiration
   - Glottis closure
   - Early termination
   - Hesitant start of test
   - Obstructed mouthpiece or breathing tube
   - Leak around mouthpiece
   - Not at TLC prior to expiration
   - Operator changed maneuver designation from acceptable to unacceptable [*prompt for reason*]
   - Other [*prompt for description*]

3. **Relating to bronchodilator responsiveness testing**
   - Facility bronchodilator responsiveness protocol followed for type, dose and delivery method of bronchodilator and wait time before post-BD testing
   - Post-BD measurements obtained using other bronchodilator(s), dose(s), delivery method or wait time. [*prompt for bronchodilator(s), dose(s), delivery method and wait time*]
   - Other [*prompt for description*]

4. **Relating to quality of testing session**
   - No comments
   - Acceptability and/or repeatability criteria not met despite patient’s best efforts
   - Spirometry induced bronchospasm
   - Patient was too tired to continue
   - FEV1 dropped more than 20% from baseline
   - Motivation difficulties
   - Coordination difficulties
   - Other [*prompt for description*]
Spirometry systems should allow users to add other standardized comments which may be required in their particular applications.

For part 1, **Other** should include information of any deviation from standard protocol, e.g. patient tested standing; ulna length or arm span used to estimate height; patient did not use nose clip; etc. If birth sex and/or ethnicity data are not disclosed, state which default values were used for calculating predicted values. For those patients requiring non-invasive adjustments such as a sealing face mask, tubing connectors or occlusion valves (e.g. patients with tracheostomy or nasal resection), a brief description of how the spirometer was adapted, including the diameter of the smallest connector used to adapt the patient to the spirometer should be included in the notes. Diameters smaller than the diameter of the subject’s trachea (13mm-26mm in males, 10mm-22mm in females) may limit flow (PEF) and FEV\(_1\) and alter the shape of the flow-volume curve.

For part 3, **Other** should include any deviation from the default bronchodilator responsiveness testing protocol used by the facility that has not otherwise been entered.

Spirometry system software should provide pop-up windows allowing the operator to click on the appropriate comments as follows:
- Part 1 – when patient information is entered
- Part 2 – at the completion of each maneuver
- Part 3 – just prior to post-bronchodilator testing
- Part 4 – at the completion of the testing session
Section E12: Limitations

These standards do not address the use of unattended spirometry for applications such as home monitoring (73-75). Spirometers used only for unattended spirometry are required to meet the current ISO 26782 performance standards (14). If spirometers do not meet the full spirometry standards (1), then the reliability of the results obtained will be diminished.

Many of the individuals with the most knowledge about the technical capabilities and limitations of spirometry systems are working for companies that manufacture spirometers. To avoid any perceived conflict of interest, these individuals were not invited to participate in the development or revision of these technical standards, and this document did not benefit from their expertise.

Public release of these standards will not occur until publication, and hence feedback from the thousands of knowledgeable and insightful operators, managers and directors conducting spirometry is not available to inform these standards. However, any key omissions or errors reported to the task force following publication will be addressed in a timely manner.

The ATS/ERS standards for interpretation of spirometry (76) will be revised after these technical standards have been published. There may be new technical requirements that arise in the updated interpretation standards that were not anticipated.
Section E13: References

1. Graham BL, Steenbruggen I, Miller MR, Barjaktarevic IZ, Cooper BG, Hall GL, Hallstrand TS, Kaminsky DA, McCarthy K, McCormack MC, Oropez CE, Rosenfeld M, Stanojevic S, Swanney MP, Thompson BR. Standardization of Spirometry – 2019 Update: An Official American Thoracic Society and European Respiratory Society Technical Statement. Am J Respir Crit Care Med, In press.

2. Miller MR, Hankinson JL, Brusasco V, et al. Standardisation of spirometry. Eur Respir J 2005;26:319-338.

3. Cooper BG. An update on contraindications for lung function testing. Thorax 2011;66:714-723.

4. Coates AL, Graham BL, McFadden RG, et al. Spirometry in primary care. Can Resp J 2013;20:13-21.

5. Vieira GM, Oliveira HB, de Andrade DT, Bottaro M, Ritch R. Intraocular pressure variation during weight lifting. Arch Ophthalmol 2006;124:1251-1254.

6. Tiller NB, Simpson AJ. Effect of spirometry on intra-thoracic pressures. BMC Res Notes 2018;11:110.

7. Boerrigter BG, Bogaard HJ, Vonk-Noordegraaf A. Spirometry in chronic obstructive pulmonary disease: a hemodynamic roller coaster?. Am J Respir Crit Care Med 2012;186:e6-e7.

8. Roberts C, Ward S, Walsted E, Hull JS. Safety of pulmonary function testing: data from 20 years. Thorax 2018;73:385-387.

9. García-Río F, Calle M, Burgos F, et al. Spirometry. Spanish Society of Pulmonology and Thoracic Surgery (SEPAR). Arch Bronconeumol 2013;49:388-401.

10. Araújo CG, Vianna LC. How often does spirometry testing induce cardiac arrhythmias?. Prim Care Respir J 2009;18:185-188.

11. Zagami D, Wilson J, Bodger A, Sriram KB. Respiratory function testing is safe in patients with abdominal aortic aneurysms. Vasc Endovascular Surg 2014;48:522-523.

12. Goodyear S, Yow H, Saedon M, et al. Risk stratification by pre-operative cardiopulmonary exercise testing improves outcomes following elective abdominal aortic aneurysm surgery: a cohort study. Perioper Med (Lond) 2013;2:10.

13. Frost F, Peat R, McWear J, et al. Pulmonary function testing is safe in patients with thoracic aortic aneurysms.. Eur Respir J 2018;52:1800928.

14. International Organization for Standardization, ISO 26782 Anaesthetic and respiratory equipment — Spirometers intended for the measurement of time forced expired volumes in humans. International Organization for Standardization, Geneva, Switzerland, 2016.

15. McCormack MC, Shade D, Wise RA. Spirometer calibration checks: is 3.5% good enough?. Chest 2007;131:1486-1493.

16. Lefebvre O, Vandergoten T, Derom E, et al. Testing spirometers: are the standard curves of the American Thoracic Society sufficient? Respir Care 2014;59:1895-1904.
17 Miller MR, Lloyd J, Bright P. Recording flow in the first second of a maximal forced expiratory manoeuvre: influence of frequency content. Eur Respir J 2002;19:530-533.

18 Haynes JM, Ruppel GL. Should spirometer quality control be treated like other laboratory devices?. ERJ Open Res 2019;5:00249-2018.

19 Westgard JO, Groth T, Aronsson T, et al. Performance characteristics of rules for internal quality control: probabilities for false rejection and error detection. Clin Chem 1977;23:1857-1867.

20 Madsen F. Validation of spirometer calibration syringes. Scand J Clin Lab Invest 2012;72:608-613.

21 Ruppel GL, Enright PL. Pulmonary function testing. Respir Care 2012;57:165-75.

22 Cooper BG, Steenbruggen I, Mitchell S, et al. HERMES Spirometry: the European Spirometry Driving Licence. Breathe 2011;7:258-275.

23 Steenbruggen I, Mitchell S, Severin T, et al. Harmonising spirometry education with HERMES: training a new generation of qualified spirometry practitioners across Europe. European Respiratory Journal 2011;37:479-481.

24 Swanney MP, O'Dea CA, Ingram ER, et al. Spirometry training courses: Content, delivery and assessment - a position statement from the Australian and New Zealand Society of Respiratory Science. Respirology 2017;22:1430-1435.

25 Borg BM, Hartley MT, Fisher M, Thompson BR. Spirometry training does not guarantee valid results. Respir Care 2010;55:689-694.

26 Represas-Represas C, Botana-Rial M, Leiro-Fernández V, et al. Short- and Long-Term Effectiveness of a Supervised Training Program in Spirometry Use for Primary Care Professionals. Arch Bronconeumol 2013;49:378-382.

27 Haynes JM. Quality Assurance of the Pulmonary Function Technologist. Respir Care 2012;57:114-126.

28 McKibben JM, McKay RT, Freeman AG, et al. Redefining spirometry hesitating start criteria based on the ratio of extrapolated volume to timed FEVs. Chest 2011;140:164-169.

29 Müller-Brandes C, Krämer U, Gappa M, et al. LUNOKID: can numerical American Thoracic Society/European Respiratory Society quality criteria replace visual inspection of spirometry?. Eur Respir J 2014;43:1347-1356.

30 National Institute for Occupational Safety and Health, Spirometry Quality Assurance: Common Errors and Their Impact on Test Results. DHHS (NIOSH) Publication Number 2012-116, 2012. Available from https://www.cdc.gov/niosh/docs/2012-116/pdfs/2012-116.pdf Accessed May 5th 2019.

31 Miller MR, Pedersen OF, Quanjer PH. The rise and dwell time for peak expiratory flow in patients with and without airflow limitation. Am J Respir Crit Care Med 1998;158:23–27.

32 Glover R, Cooper B, Lloyd J. Forced expiratory time (FET) as an indicator for airways obstruction. European Respiratory Journal 2014;44:Suppl 58:P1819.
33 Giner J, Plaza V, Rigau J, et al. Spirometric Standards and Patient Characteristics: An Exploratory Study of Factors Affecting Fulfillment in Routine Clinical Practice. Respiratory Care 2014;59:1832-1837.

34 Sumphao-Ngern P, Foocharoen C, Boonsawat W, et al. Causes and prevalence of inadequate pulmonary function testing among patients with systemic sclerosis. Arch Med Sci 2015;11:1255-1260.

35 Czajkowska-Malinowska M, Tomalak W, J. Radliński. Quality of spirometry in the elderly. Pneumonol Alergol Pol 2013;81:511-517.

36 Hankinson JL, Eschenbacher B, Townsend M, Stocks J, Quanjer P. Use of forced vital capacity and forced expiratory volume in 1 second quality criteria for determining a valid test. European Respiratory Journal 2015;45:1283-1292.

37 Torre-Bouscoulet L, Velázquez-Uncal M, García-Torrentera R, Gochicoa-Rangel L, Fernández-Plata R, Enright P, Pérez-Padilla R. Spirometry quality in adults with very severe lung function impairment. Respiratory Care 2015;60:740-743.

38 Enright PL, Vollmer WM, Lamprecht B, et al. Quality of spirometry tests performed by 9893 adults in 14 countries: the BOLD Study. Respir Med 2011;105:1507-1515.

39 Tan WC, Bourbeau J, O'Donnell D, et al. Quality assurance of spirometry in a population-based study -predictors of good outcome in spirometry testing. COPD 2014;11:143-151.

40 Janssens W, Liu Y, Liu D, Kesten S, Tashkin DP, Celli BR, Decramer M. Quality and reproducibility of spirometry in COPD patients in a randomized trial (UPLIFT®). Respir Med 2013;107:1409-1416.

41 Tomalak W, Radliński J, Latawiec W. The quality of spirometric measurements in children younger than 10 years of age in the light of the recommendations. Pneumonol Alergol Pol 2008;76:421-425.

42 Hankinson JL, Bang KM. Acceptability and reproducibility criteria of the American Thoracic Society as observed in a sample of the general population. Am Rev Respir Dis 1991;143:516–521.

43 Kirkby J, Welsh L, Lum S, et al. The EPICure study: comparison of pediatric spirometry in community and laboratory settings. Pediatr Pulmonol 2008;43:1233-1241.

44 Enright PL, Beck KC, Sherrill DL. Repeatability of spirometry in 18,000 adult patients. Am J Respir Crit Care Med 2004;169:235-238.

45 Gochicoa-Rangel L, Vargas-Domínguez C, García-Mujica ME, et al. Quality of spirometry in 5-to-8-year-old children. Pediatr Pulmonol 2013;48:1231-1236.

46 Dorinsky PM, Reisner C, Ferguson GT, et al. The combination of ipratropium and albuterol optimizes pulmonary function reversibility testing in patients with COPD. Chest 1999;115:966–971.

47 Tashkin DP, Celli B, Decramer M, et al. Bronchodilator responsiveness in patients with COPD. Eur Respir J 2008;31, p. 742–750.
48 Ditcham W, Murdzoska J, Zhang G, et al. Lung deposition of 99mTc-radiolabeled albuterol delivered through a pressurized metered dose inhaler and spacer with facemask or mouthpiece in children with asthma. J Aerosol Med Pulm Drug Deliv 2014;27:S63-S75.

49 D’Vaz N, Okitika TA, Shackleton C, Devadason SG, Hall GL. Bronchodilator responsiveness in children with asthma is not influenced by spacer device selection. Pediatric Pulmonology 2019;54:531-536.

50 Rodriguez-Martinez CE, Sossa-Briceño MP, Castro-Rodriguez JA. Comparison of the bronchodilating effects of albuterol delivered by valved vs. non-valved spacers in pediatric asthma. Pediatr Allergy Immunol 2012;23:629-635.

51 Schultz A, Le Souëf TJ, Venter A, et al. Aerosol inhalation from spacers and valved holding chambers requires few tidal breaths for children. Pediatrics 2010;126:e1493-e1498.

52 Stavreska V, Verheggen M, Oostryck J, Stick SM, Hall GL. Determining the time to maximal bronchodilator response in asthmatic children. J Asthma 2009;46:25-29.

53 Cogen JD, DiBlasi RM, Gibson RL, Debley JS. Effect of extending the time after bronchodilator administration on identifying bronchodilator responsiveness in a pediatric pulmonary clinic. Pediatr Pulmonol 2017;52:984-989.

54 Gardenhire DS, Burnett D, Strickland S, Myers TR. A Guide To Aerosol Delivery Devices for Respiratory Therapists, 4th Edition. American Association for Respiratory Care, 2017.

55 Borg BM, Reid DW, Walters EH, Johns DP. Bronchodilator reversibility testing: laboratory practices in Australia and New Zealand. Medical Journal of Australia 2004;180:610-613.

56 Barjaktarevic IZ, Kaner R, Buhr RG, Cooper CB. Bronchodilator Responsiveness or Reversibility in Asthma and COPD – A Need for Clarity. Int J Chron Obstruct Pulmon Dis 2018; 13:3511-3513.

57 Davis BE, Blais CM, Cockcroft DW. Methacholine challenge testing: comparative pharmacology. J Asthma Allergy 2018;11:89-99.

58 LaForce C, Korenblat P, Osborne P, Dong F, Higgins M. 24-hour bronchodilator efficacy of single doses of indacaterol in patients with persistent asthma: comparison with placebo and formoterol. Curr Med Res Opin 2009;25:2353-2359.

59 Jones TE, Southcott A, Homan S. Drugs potentially affecting the extent of airways reversibility on pulmonary function testing are frequently consumed despite guidelines. Int J Chron Obstruct Pulmon Dis 2013;8:383–388.

60 Culver BH, Graham BL, Coates AL, et al. Recommendations for a Standardized Pulmonary Function Report. An Official American Thoracic Society Technical Statement. Am J Respir Crit Care Med 2017;196:1463-1472.

61 Johnston R. A modest proposal for a clinical spirometry grading system. PFT Blog:https://www.pftforum.com/blog/a-modest-proposal-for-a-clinical-spirometry-grading-system/#more-2420, 2018. Accessed May 5th 2019

62 Johns DP, Hartley MF, Burns G, Thompson BR. Variation in barometric pressure in Melbourne does not significantly affect the BTPS correction factor. Respirology 2004;9:406-408.
63 Gauld LM, Kappers J, Carlin JB, Robertson CF. Height prediction from ulna length. Developmental Medicine & Child Neurology 2004;46:475-480.

64 Barbosa VM, Stratton RJ, Lafuente E, Elia M. Ulna length to predict height in English and Portuguese patient populations. Eur J Clin Nutr 2012;66:209-215.

65 Weidauer L, Wey H, Slater H, Moyer-Mileur L, Specker B. Estimation of length or height in infants and young children using ulnar and lower leg length with dual-energy X-ray absorptiometry validation. Dev Med Child Neurol 2014;56:995-1000.

66 Chen WY, Lin YT, Chen Y, et al. Reference equations for predicting standing height of children by using arm span or forearm length as an index. J Chin Med Assoc 2018;81:649-656.

67 Bonell A, Huyen NN, PhuVD, Wertheim H, Nadjm B. Determining the predictive equation for height from ulnar length in the Vietnamese population. Asia Pac J Clin Nutr 2017;26:982-986.

68 Elia M. The ‘MUST’ Report. Nutritional Screening of Adults: A Multidisciplinary Responsibility. Development and Use of the ‘Malnutrition Universal Screening Tool’ (‘MUST’) for Adults. British Association of Parenteral and Enteral Nutrition, 2003.

69 Quanjer PH, Capderou A, Mazicioglu MM, et al. All-age relationship between arm span and height in different ethnic groups. European Respiratory Journal 2014;44:905-912.

70 Quanjer PH, Stanojevic S, Cole T, et al. Multi-ethnic reference values for spirometry for the 3-95 year age range: the global lung function 2012 equations. Eur Respir J 2012;40:1324-1343.

71 Lum S, Bountziouka V, Quanjer PH, et al. Challenges in Collating Spirometry Reference Data for South-Asian Children: An Observational Study. PLoS One 2016;11:e0154336.

72 Wanger J, Mottram C. ATS Pulmonary Function Laboratory Management and Procedure Manual 3rd Edition. New York, American Thoracic Society, 2016.

73 Russell AM, Adamali H, Molyneaux PL, et al. Daily Home Spirometry: An Effective Tool for Detecting Progression in Idiopathic Pulmonary Fibrosis. Am J Respir Crit Care Med 2016;194:989–997.

74 Wang W, Finkelstein SM, Hertz MI. Automatic event detection in lung transplant recipients based on home monitoring of spirometry and symptoms. Telemed J E Health 2013;19:658-663.

75 Murgia F, Bianciardi F, Solvol T, et al. Telemedicine Home Program in Patients with Cystic Fibrosis: Results after 10 Years. Clin Ter 2015;166:e384-e388.

76 Pellegrino R, Viegi G, Brusasco V, et al. Interpretative strategies for lung function tests. Eur Respir J 2005;26:948-968.